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THE AMERICAN WELDING SOCIETY JOURNAL

VOLUME 14 AUGUST 1935 NUMBER 8

PUBLISHED MONTHLY FOR THE ADVANCEMENT OF THE SCIENCE AND ART OF WELDING

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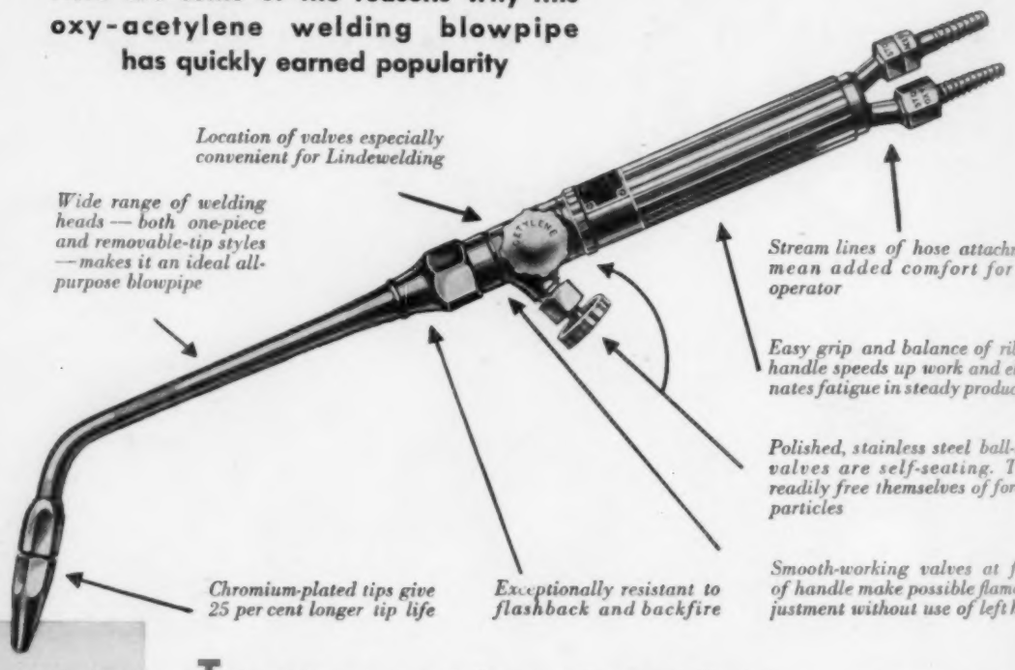
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ISSUED MONTHLY

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Largest All-Welded Bridge Completed in New Jersey

By A. F. DAVIS†

PROBABLY the largest truss bridge ever built in the United States by welding and probably one of the two largest all-welded truss bridges in the world, has just been completed across the Rancocas River, connecting Riverside and Delanco, New Jersey. Erected by the shielded arc process of electric welding, 450 tons of structural steel were fused into one continuous structure at a saving of approximately 15% in weight.

Built at a cost of $270,890, the Riverside-Delanco bridge (see Fig. 1) is 397 feet long with a roadway 36 feet wide between curbs and one sidewalk 5 feet in width from the center line of the bridge truss to center line of the hand rail. The width of the bridge, measured from center to center of trusses is 38 feet 6 inches. The bridge is supported on five piers, two abutments, two intermediates and one center pier. (See Fig. 2.)

† Vice-President, The Lincoln Electric Company.

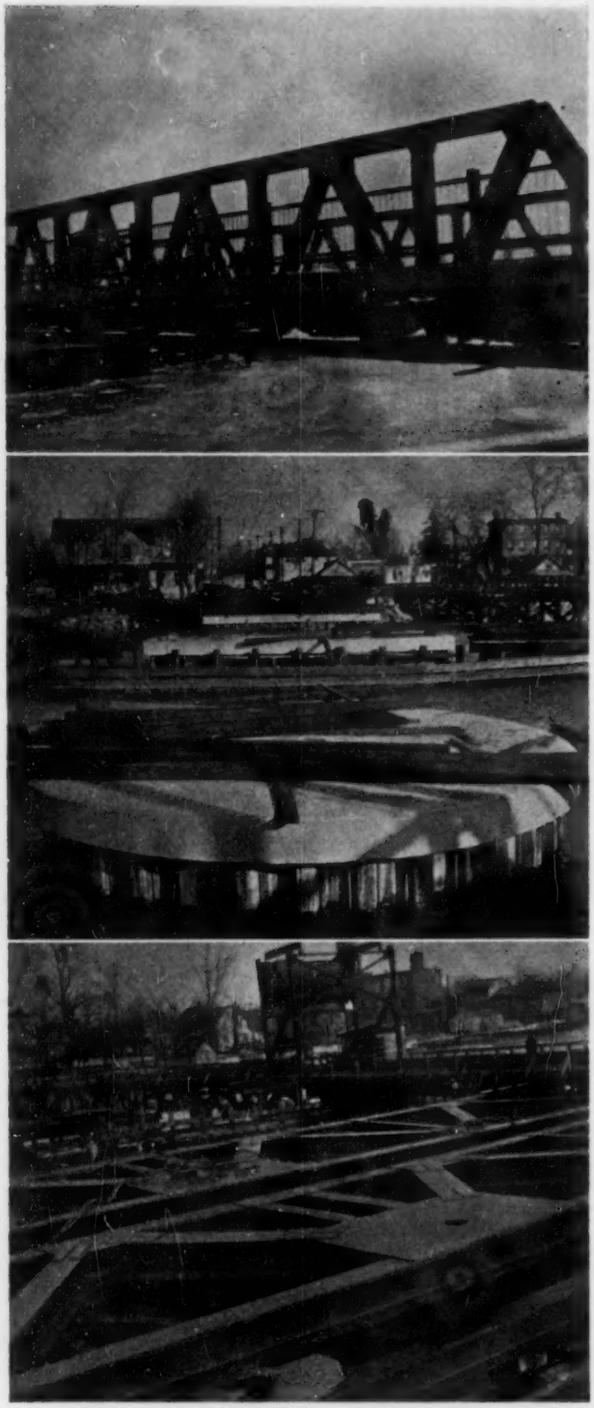


Fig. 1—View of One of the Fixed Spans of the 397-foot Riverside-Delanco Bridge Largest All-Welded Bridge Ever Built in the United States. Shielded Arc Welding Saved Approximately 15% in Weight

Fig. 2—Three of the Five Main Pier Supports of the Bridge. The Structural Steel Supports of the Coffordams Were Arc Welded to the Side Walls

Fig. 3—Two of Three Sections of One Center Truss of the All-Welded Riverside-Delanco Bridge Fabricated in the Shop by Shielded Arc Welding and Delivered to the Bridge Site Ready for Erection

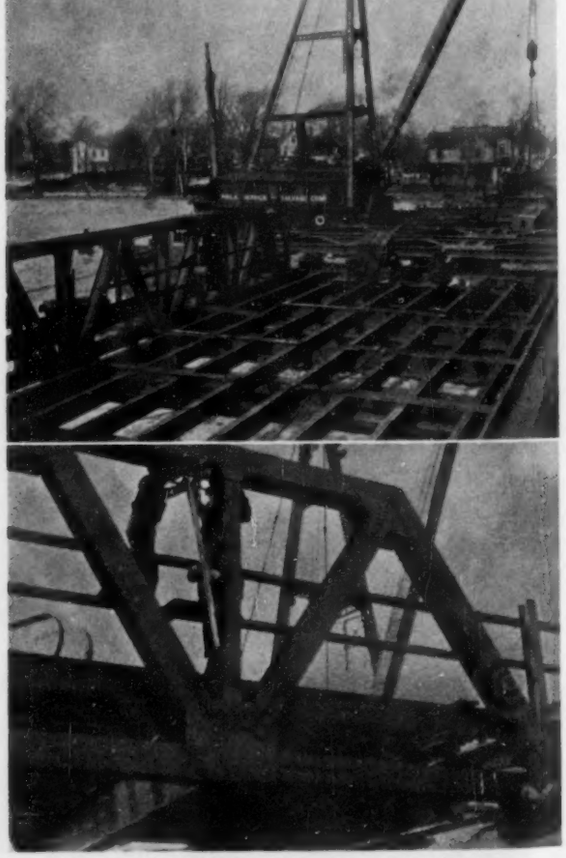


Fig. 4—Assembling the Center Trusses of the Bridge. In the Foreground and Background Can Be Seen the Two Fixed Approach Spans, Each 112 Feet 8 Inches Long

Fig. 5—Close-Up of Truss. Use of Arc Welding in Fabrication of These Trusses Permitted a Saving of Approximately 15% in Total Weight

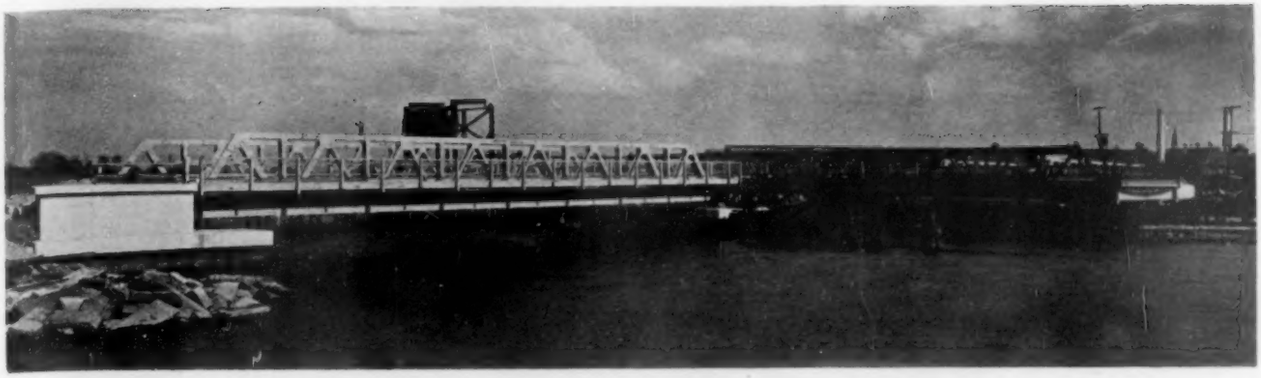


Fig. 6—Photo Taken May 31st Showing the New Riverside-Delanco Bridge Across the Rancocas River, New Jersey, Practically Completed. This Is the Largest All-Welded Truss Bridge in the United States, Second Largest in the World. Welded Entirely by the Arc Process

The steel frame of the bridge is made up of three spans, two of which are approach fixed spans and one swing span. The two fixed spans each measure 112 feet 8 inches center to center between end bearings with two spaces 4 feet 6 inches long over the piers. The swing span is 160 feet long center to center between end bearings. These spans, totaling 385 feet 4 inches in length, added to 9 feet for the two spaces over the piers and two spaces totaling 2 feet 8 inches between center line of end bearings and back wall, make the total length of the bridge 397 feet.

Each truss of the two approach spans was fabricated as a complete truss member in the shop by arc welding before shipment to the job. Shop welding was also employed in fabricating the trusses of the swinging span (see Fig. 3), which were welded up in three sections. These sections were later welded in the field into one truss for the center span (see Figs. 4 and 5).

The saving in weight made possible by arc welding principally in the chord and web members of the trusses, permitted a total saving of approximately 10 to 15% in weight of the structural steel of the bridge.

A total of 24,000 lineal feet of welding was required in fabricating and erecting the structural steel. Of this amount 15,000 feet of $^{5}/_{16}$-inch full fillet welds were required in the shop fabrication, all of which was done by the American Bridge Company at Ambridge, Pennsylvania. The field welding, which amounted to 9000 lineal feet of $^{5}/_{16}$-inch full fillet welds, was done by the J. K. Welding Company of New York City. Shop fabrication was done with motor generator type of welding equipment while gas engine driven machines were used in the field.

The contract for the Riverside-Delanco bridge was let January 29, 1934, to the Kolyn Construction Company of Trenton, N. J. Contract for the superstructure was sublet to the American Bridge Company and the contract for the field welding was sublet to the J. K. Welding Company, New York City. Construction Engineers on the project were the Bridgeweld Engineering Company, New York, represented by H. B. Mish of New York City. Figure 6 shows the bridge as it neared completion May 31st.

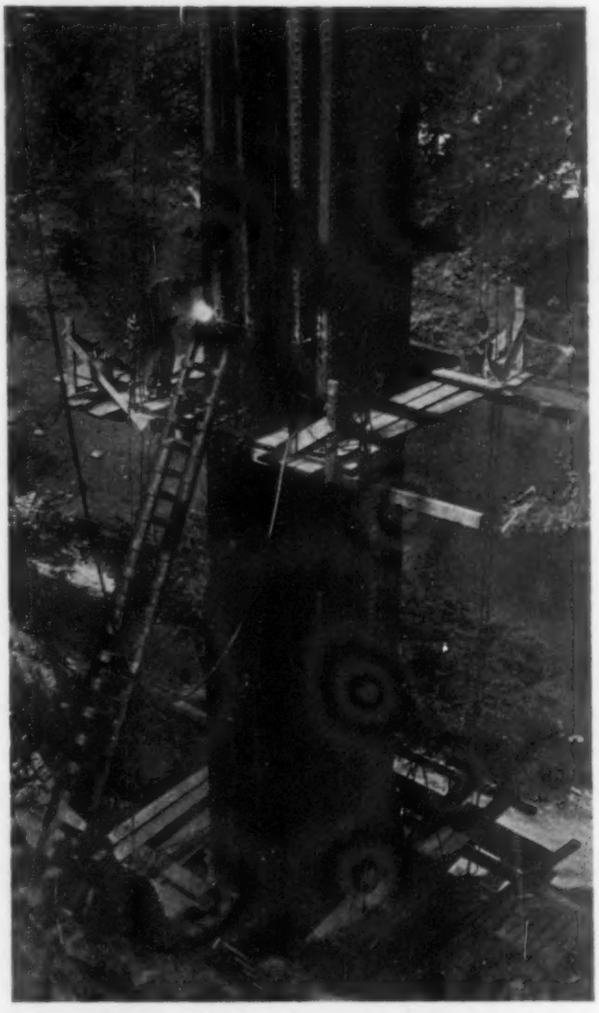


Fig. 7—The Electric Arc Being Used in Construction of Cleveland's New $500,000 Bridge. This Bridge Is the First of Its Type Ever Built. Though Steel Is Used Throughout, the Finished Appearance Will Be That of Concrete.

Arc Welding Used in Construction of New Cleveland Bridge

A new bridge, the first of its type ever constructed, whose towers, arches and general appearance suggest concrete, yet whose framework is entirely of steel, is under construction over the Rocky River valley on Lorain Road, Cleveland, Ohio. Arc welding is being used extensively in construction.

The new bridge which is to cost approximately $500,000, replaces a pin-connected truss bridge and is of the open spandrel steel arch type, 1260.89 feet long overall. All structural steel is copper bearing.

The roadway of the new bridge is 40 feet wide, with a five-foot concrete sidewalk on either side.

The bridge is supported on five 30-ton shop-fabricated floor beams carried on five pairs of steel towers, each resting on a concrete substructure and anchored to grilling embedded in the concrete.

The towers at each end of the bridge comprise two 30-foot sections. The three intermediate pairs of towers comprise three of these 30-foot sections. Each section weighs 30 tons. The sections are butt welded together in the field.

A total of 34 feet of welding is required in each butt joint. There are two of these butt welds in each of the four end towers, and three in each of the six intermediate towers, making a total of 26 butt welds, each containing 34 lineal feet of welding. Figure 7 shows a butt weld being made on one of the towers.

Arc welding is also being used in attaching the boss plates which tie the floor beams together. There are 350 of these plates. Figure 8 (illustration on front cover) shows arc welding being done on a floor beam. Welding is being employed also in construction of the arches, light standards and railings.

All welds used in building the bridge are required to show a tensile strength of 60,000 lb. per sq. in. The bridge is scheduled for completion by November 1. The Peoples Steel Company, Cleveland, are erecting the steel. The Lowenshon Construction Company, Cleveland, are the contractors.

The Development of Weld Testing as Indicated by Published Literature*

By M. F. SAYRE†

THE volume of published literature forms a relatively accurate guide as to the flow of interest from year to year and in different countries in welding. A recent study of the present status of information regarding weld testing, an incidental part of which was the preparation of a bibliography containing over 700 references, gives some interesting information regarding this point.

These references, taken from the Engineering Index, the Industrial Arts Index, the British Institute of Metals Abstracts, and the Iron and Steel Institute Abstracts, and supplemented by information obtained elsewhere, while naturally emphasizing German, English and American periodicals, apparently cover with a reasonable degree of care literature throughout the entire world. As shown in Table I, interest was relatively mild up to 1927 but thereafter rapidly increased, reaching a peak through 1932 to 1934. The depression evidently acted in a favorable sense rather than otherwise, possibly by giving more time to write up experimental results which had previously been obtained. Germany and the United States share about evenly in the volume and incidentally also in the quality of material published. Articles in English magazines total about a third of those in either Germany or the United States, but have an importance greater than the comparative number indicates. France ranks fourth with only a quarter as many as in England.

The accompanying lists are given as a possible convenient guide for other investigators, giving the names of the journals in which the major number of these articles were published. The figure given following the name of each journal indicates the number of references dealing in one way or another with weld testing published in it during the period 1923 to 1934. It will be noted that the *American Welding Society Journal*, as would be expected, stands first, while the German *Die Elektroschweissung*, first published in 1930, has risen to the second rank. These lists do not include all of the journals interested in welding, since many valuable periodicals have given their major attention to other phases than that of weld testing, which this investigation specifically emphasized. Some of these other magazines are given in the accompanying list.

A cursory study of the bibliography suggests the following statements regarding the status of information in the various fields covered:

Tension testing of butt welds follows in general the methods that have been developed in connection with tension testing in general. These methods as relating to homogeneous metals have been well standardized. In addition much experimental work has been done and many articles have been written referring specifically to tension testing of welds. There seems therefore to be no drastic need for further work in this direction.

Very little work has been done on compression testing of welds and but little is known on this subject. The subject is not a vitally important one but further work is desirable.

As compared to the importance of the subject there is but little published material on methods of shear testing. Such problems as bettering the stress distribution along the length of a shear or fillet weld would seem to

* A contribution to the Fundamental Research Committee of the A. B. W.
† Associate Professor of Applied Mechanics, Union College, Schenectady, N.Y.

Table 1—Interest in Weld Testing as Indicated by Published Matter

Country of Publication	No. of Pub.	Number of References 1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	Total
United States	53	2	1	5	5	12	10	27	33	28	48	41	36	248
Germany	44	1	1	3	1	3	18	17	19	37	50	75	59	284
England	23	1	1	1	0	2	10	3	11	14	15	21	11	90
France	11				1	2	4	2	1	2	5	2	3	22
Canada	5								2	0	2	1	1	6
Italy	3										1	1	3	5
Russia	3										3	1	0	4
Japan	3						1	0	1	0	0	4	0	6
International	3								10	1	1	0	2	14
Australia	2										2	1	0	3
Switzerland	2			1	0	0	3	0	0	0	8	2	0	14
Brazil	1							1	0	0	0	0	0	1
Total	143	4	3	10	7	19	46	50	77	82	135	149	115	697

Table 2—Journals Devoted to Welding

	References on Weld Testing, 1923–1934
United States	
American Welding Society Journal (New York)	94
Welding Engineer (Chicago)	26
Welding (Pittsburgh)	14
England	
Welding Journal (London)	7
Welder (London)	7
Welding Industry (London)	3
Electric Welding (London)	3
Germany	
Die Elektroschweissung (Braunschneig)	62
Autogene Metallbearbeitung (Halle)	26
Schmelzschweissung (Halle)	6
Autogene Schweisser (Halle)	2
France	
Revue Soudure Autogene (Paris)	2
Soudure-Coupeur (Paris)	1
Switzerland	
Zeitschrift für Schweisstechnik, Journal de la Soudure (Basel)	6
Australia	
Mechanical and Welding Engineer (Melbourne)	2
Russia	
Autogennoye Dyelo	2

call for further investigation. Certain experimental work carried on at the General Electric Company also points to the possibility of simplifying the form of test specimens while simultaneously rendering the test more accurate and more significant.

Torsion testing has received but little attention. Further experimental work is needed both in connection with simple test bars in torsion and with the torsional behavior of built-up frame-works.

The methods used in determining the abrasion, scratch or Brinell hardness of welds differ but little from those applied in the hardness testing of homogeneous metals. Hardness values may be serviceable either as a measure of probable ultimate strength or as a measure of probable resistance to abrasive wear. Alternatively, comparative hardness values of the deposited weld metal, of the metal in the parent piece immediately adjacent to the weld, and of metal in this same piece some distance away from the weld may aid somewhat in determining the relative strength of different portions of the weld. Ten articles appeared on this subject during 1930 but interest since then appears to have waned.

Impact testing of welds in recent years has attracted a very large amount of attention both in connection with methods of making the test and of the interpretation of test values thereafter. The theory of impact testing of welds is so closely tied up with the theory of impact testing in general as to suggest that what is really needed is a thorough-going attack on the general problem of impact testing. Recent studies both in the United States and in Germany promise to shed further light on this subject.

Fatigue testing of welds is also so closely tied up with the general subject of fatigue testing and so much work has been done on this general subject that experimental work rather than theoretical study on fatigue testing of welds seems to be what is needed. There are over a hundred papers on fatigue testing listed in the bibliography. This includes all those papers which referred directly to test of welds but only a small percentage of the much larger number which could have been listed if attempt had been made to cover fatigue testing methods in general.

Only seven papers were found which referred to creep testing of welds. There is probably need for further work in this direction. The use of specific gravity as a means of determining percentages of voids in a weld was described in only four papers.

The imposing list of papers on X-ray and Gamma-ray reflects the amount of interest which has been directed to this subject. This is a very special field and no attempt has been made to study these papers, nor the papers on various proposed methods of magnetic testing.

The so-called plunger-roller method of weld bend testing is used throughout Europe as contrasted to the free bend method in this country. Proposals have also been made for a modified free bend which might be spoken of as the "uniform moment" method in which the weld is subjected to a bending moment only without shear or compression components. This has distinct theoretical advantages but certain practical disadvantages. All three methods have been extensively studied experimentally but this information is scattered throughout English, German and American publications. A study of this available information with a view to comparing the merits of the different methods is probably of more importance at the present time than the carrying on of further experimental work. Such a digest has been prepared as a part of this investigation and will be published in the near future.

The detail work in connection with the bibliography and the preparation of translations and abstracts was carried on by Mr. Herman Munz at Union College with aid from the National Research Council, under the general direction of a committee composed of Professor M. F. Sayre, Union College, Mr. Andrew Vogel, General Electric Company, and Mr. H. M. Hobart, Chairman of

Table 3—Journals With 7 or More References to Weld Testing

	1923–1934
United States	
American Society for Testing Materials	14
Boiler Maker	8
Acetylene Journal	7
Germany	
Zeitschrift, Vereines Deutscher Ingenieure	41
Waerme	12
Stahl und Eisen	11
Stahlbau	9
Archiv für Eisenhuttenweisen	8
England	
Engineering	13
Metallurgist (Supplement to Engineer)	10
Iron and Steel Institute	7

Table 4—Other Sources for Welding Information

United States	
Oxy-acetylene Tips	New York
Industry and Welding	Cleveland
Germany	
Acetylen in Wissenschaft und Industrie	Halle
Svarochiny Vestnik	Berlin
Arcos Zeitschrift	Aachen
England	
Welding News	London
Acetylene and Welding Journal	London
Poland	
Spawanie i Ciecie Metali	Warsaw
Hungary	
Acetilén és Karbid	Budapest

the Committee on Fundamental Research of the American Welding Society. Copy of the complete bibliography on weld testing has been placed on file at Carnegie Library, Pittsburgh, Engineering Societies Library, New York, and the American Welding Society. Each article in the bibliography is keyed so as to indicate the particular phases of weld testing which are treated, and in addition in most cases a brief abstract is included.

High Voltage Condenser Welding

By ENG. G. I. BABAT†

SPOT welding has been known for more than 30 years. In all the existing types of machines for spot welding the feeding of the welding transformer is being done by single-phase standard frequency current (50 or 60 cycles), as it was done in the first years of its existence.

To improve the quality of certain welds it is necessary to cut the duration of the welding current for each spot—the welding time—as short as possible. This is the reason why different complex mechanical contactors are applied. Some advances in resistance welding have been made with thyratron and similar controls.

In practice the shortest welding time obtainable is $^1/_4$ of a cycle of the A.C. feeding the welding transformer, i.e., the shortest welding time may be 0.01 sec.[1]

Moreover the mechanical contactors as well as the thyratron controllers have one great disadvantage: they measure off only the welding time but not the energy given to each spot. And the welding machines measuring the energy absorbed by each welded spot operate at the welding time, time no less than 10–20 cycles of A.C., i.e., about 0.2–0.5 sec.

In order to pass over to the welding time at the rate of a 1000th or even a 10000th part of a second and in order to be able to measure off exactly the energy consumed by every welded spot, it is necessary to give up the A.C. feeding of the welding transformer and to look for some other methods.

Therefore the method of resistance welding described here and entitled by the author as "High Voltage Condenser Welding," presents some interest to us.

The main principle of this method may be gathered from Fig. 1.

The condenser C is charged to a high voltage by a rectifier fed by A.C. main (single-phase or three-phase).

† Svetlana Works, Research Laboratory, U.S.S.R.

[1] It is obvious that the method of feeding the welding transformers with the highest frequency current (as for instance 500 cycles) is impracticable. In this case special high frequency generators expensive and complicated in operation would be required.

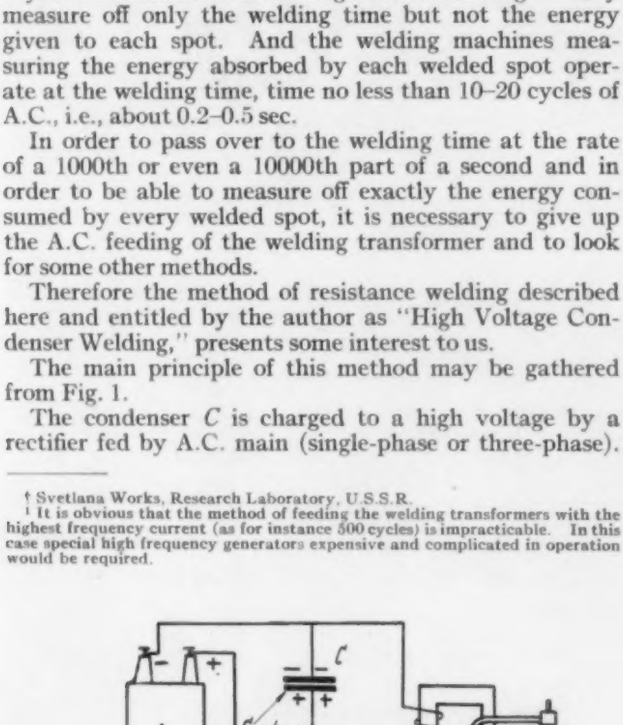


Fig. 1—Schematic Diagram of the Circuit of High Voltage Condenser Welding

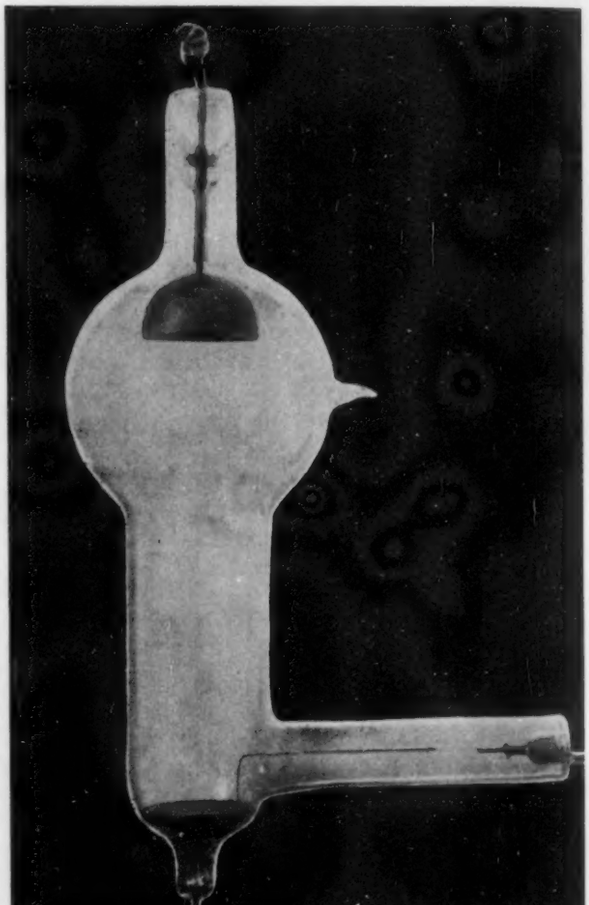


Fig. 2—Discharge Tube for High Voltage Condenser Welding

If the condenser capacity is C microfarads, and it is charged with V volts, the electrical energy stored in it in joules (watt seconds) may be expressed by the well known formula:

$$W = \frac{CV^2}{2}$$

The condenser having the capacity of some microfarads charged to the voltage of 3 to 5 kv. can store several hundreds of watt seconds, while, according to our experiments for welding stainless steel with a thickness of 0.25 mm., it is necessary to spend 20–30 watt seconds.

The principal part of the apparatus in description is a welding transformer of special construction.

The secondary winding of this transformer consists

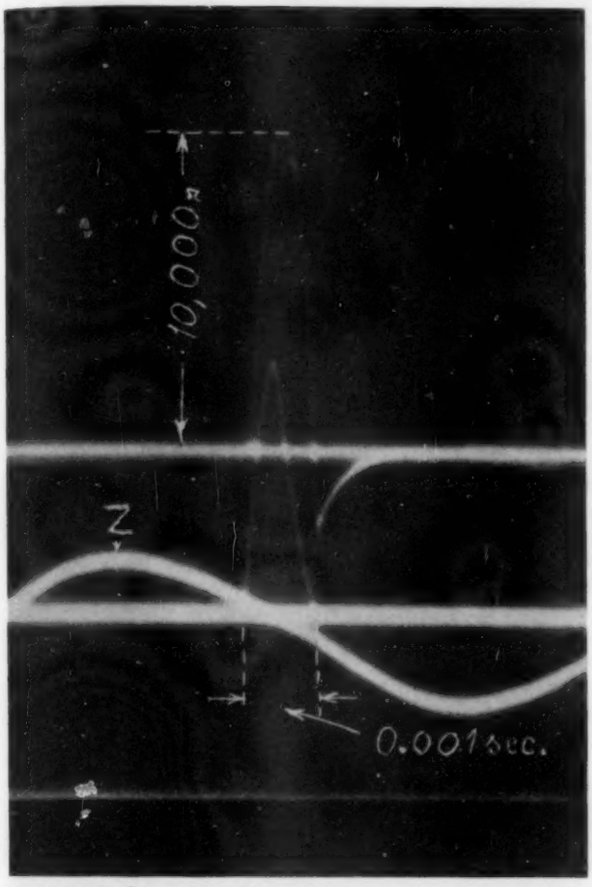


Fig. 3—The Oscillogram of the Welding Transformer Currents. The Upper Curve is the Welding Current. The Lower Curve is the Current of the Primary. Curve Z is the A.C. Voltage (50 Cycles). This Curve is Given for Comparison

of a single turn and is connected to the electrodes between which the welded details are pressed.

The charge stored in the condenser *C* may be allowed to pass through the primary winding with the help of a special discharge tube.

The discharge tube is shown in Fig. 2. The tube has a mercury cathode, which may be ignited with the help of a special igniter.

Such a discharge tube can pass through impulses of short duration of the order of several hundred amperes. When the condenser discharges through the welding transformer primary winding then the current exceeding some hundred times the current of the primary is being induced in its secondary.

With the proper design of the welding transformer it is possible to obtain the results showing that more than 90% of the energy stored in the condenser will be deposited at the welded spot. Figure 3 shows an oscillogram of the welding transformer currents. The upper curve is the current of the primary. The lower curve is the welding current.

The duration of the current impulse through the transformer secondary, i.e., the welding time, is defined by the condenser capacity and by the leakage inductance magnitude of the welding transformer. With the proper construction of the welding transformer (using the shell-type, pancake windings and chosing the correct section of an iron circuit, etc.) it is possible to decrease the transformer leakage reactances in such a way that it may become possible to obtain the duration of the welding time less than a ten thousandth part of a second.

It is very easy to regulate the inductance in the welding transformer circuit and thus to fix any welding time required.

Since the duration of the welding current is very low, the secondary voltage of the welding transformer, in the high voltage condenser welding machines should be taken much higher than that for the welding machines of a common construction; it must be done in order to give out the required quantity of energy at the welded spot.

In the welding transformers supplied by A.C. the amplitude of the secondary voltage does not exceed some volts, but according to the method described here the amplitude of the secondary voltage of the welding transformer may be of the order of scores of volts.

The regulations of the quantity of energy consumed by every welded spot may be conveniently obtained by varying either the condenser capacity or the voltage up to which it is charged. It is possible, for example, to connect a voltmeter parallel to the condenser and to scale it directly in watts.

It is necessary to note that the idea of producing welds by means of a condenser discharge is not new.

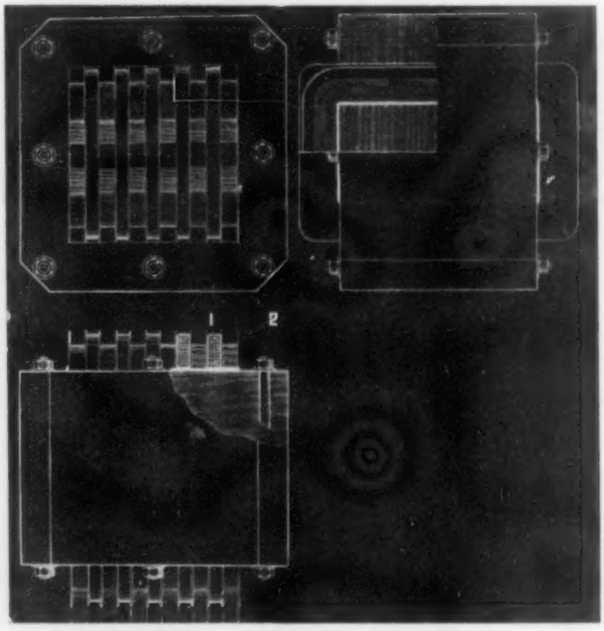
However all the earlier attempts were based upon the application of the condensers at low voltage, that is, the discharge current of a condenser was directly passed without any intermediate transformer through the welding spot.

Since the quantity of the energy stored in a condenser is proportional to the square of the voltage on its plates it is obvious that in order to store some watt seconds in a low-voltage condenser, it is necessary to take its capacity in some hundreds or even thousands of microfarads. This made the low voltage condenser welding quite limited, even when using electrolytic condensers.

Let us summarize in brief the principal advantages of the high voltage condenser welding.

(a) The quantity of energy delivered for every welded spot may be measured off with an accuracy quite unattainable by any other method and easily regulated.

(b) The welding time may be regulated quite easily and simply (the lowest limit of the welding time is the ten-thousandth part of a second). Thus for any kind of



1. Primary Winding. 2. Secondary Winding

Fig. 4—A Schematic Drawing of the Shell Type Welding Transformer for High Voltage Condenser Welding

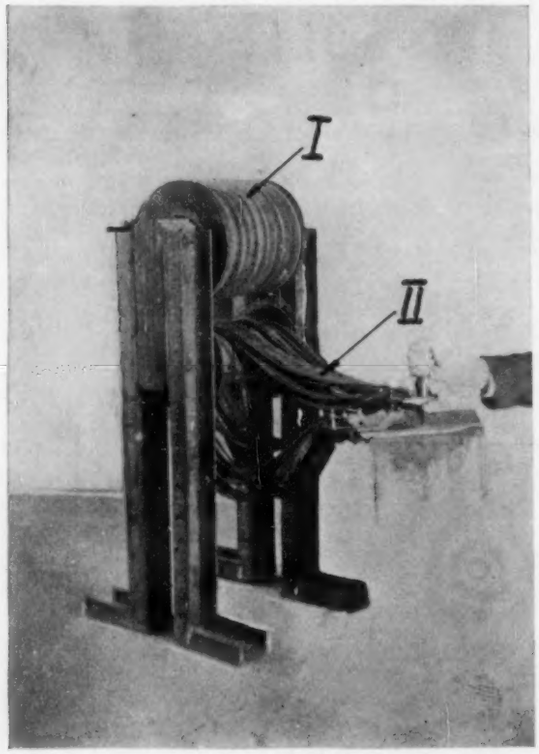


Fig. 5—The Welding Transformer Used in the Former Experiments. I. Primary. II. Secondary

welded material it is possible to chose the most suitable thermal conditions.

(c) The A.C. main is equally loaded by the machines for the high voltage condenser welding.

Though the instantaneous power developed by our welding apparatus at the moment of the condenser discharge is rather high (above some hundreds kw.), it is not obtained from the A.C. main as in the case of the usual welding apparatus, but is delivered by the condenser which stores the necessary quantity of energy during all the interval between two successive weldings. Since the absolute quantity of energy consumed by each welded spot is not very high (some scores of watt seconds), the average power consumed by the apparatus for high voltage condenser welding is also rather low and it is possible to feed the latter directly from a low power A.C. main.[2]

(d) The method of high voltage condenser welding may be applied with great success not only for spot welding, but also for line welding.

For this purpose a sufficiently powerful rectifier should be used in order to obtain the required speed in charging the condenser. The rollers are connected to the welding transformer secondary and the welded material is then passed between these rollers.

It is clear that the speed of the machine action may attain some scores of spots per second and thus it is possible to obtain the rigid and solid weld at a speed of 2–3 meters per minute by the passing of the welded material between the rollers.

[2] Moreover the rectifier may be fed from a three-phase main, therefore the given apparatus makes the load symmetrical which cannot be obtained by the usual welding machines.

A schematic drawing and the photo of the welding transformer for high voltage condenser welding are shown in Fig. 4.

The welding transformer is of shell type (Fig. 6). Its primary consists of separate well insulated sections. All the primary sections are connected in series. The secondary of the welding transformer consists of six separate turns placed between sections of the primary and connected in parallel. Each turn of the secondary consists of a set of thin copper wires. The welding electrodes are connected to the ends of the secondary winding.

The leakage inductance of this transformer is very small due to such a construction. Therefore its efficiency is very high and the welding time is of the rate of some 10,000 fractions of a second.

The sizes of this transformer (in mm.) are 280 x 280 x 250.

The described apparatus for high voltage condenser welding has been tested only in the laboratory.

By means of this apparatus we have welded stainless steel (18% Cr 8% Ni). Thickness of the sheets was from 0.1 to 0.6 mm.; the total thickness of the welded sheets was up to 1.5 mm. The condenser capacity was 10 mf.

According to the mechanical properties and general appearance of the welded spots produced by this method are superior to welds made by other methods of control.

I have also successfully welded light alloys—duralumin and superduralumin by this apparatus.

I propose to apply the high voltage condenser welding chiefly in airplane construction.

This method has the special advantages for repairing of all-metal airplanes. This method may be used in places where there is no powerful electric supply.

The high voltage condenser welding apparatus develops a big momentary power, but it may be supplied by a very small power network.

The condenser of this apparatus may be charged, for example, from a motor car magneto. The only disadvantage of this method of charging is that the charging will be produced very slowly and the intervals between separate welds will be of long duration.

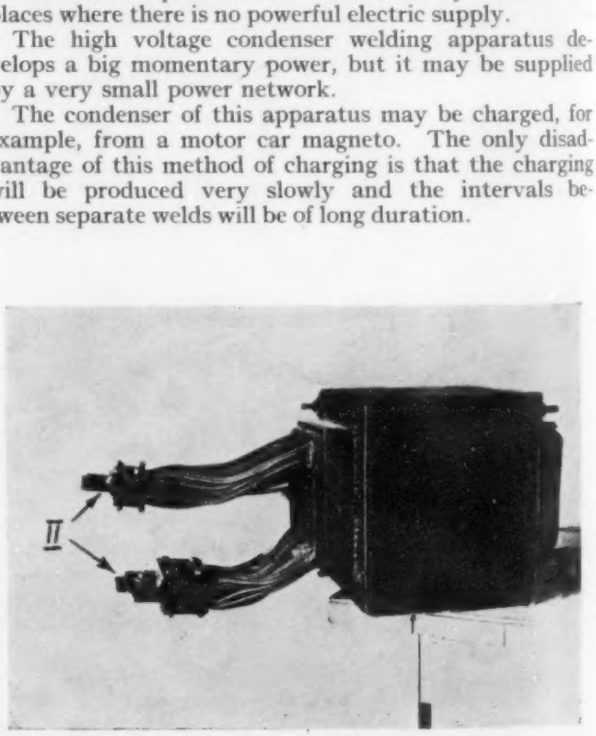


Fig. 6—The Photo of the Shell Type Welding Transformer for High Voltage Condenser Welding. II. The Ends of the Secondary to Which the Welding Electrodes Are Connected

A Note on Some Results Concerning the Variation of Chemical Composition in the Gas-Welding of Ordinary Steels*

By ALBERT M. PORTEVIN† AND A. LEROY†

BESIDES the modifications of composition and structure, as marked in heated as in fluid metal, and which link up welding to foundry operations and heat treatment, there may be modifications of the chemical composition of the fluid metal consequent upon certain chemical reactions with the surrounding medium, as happens in minute and extremely rapid metallurgical operations.

The surrounding media are constituted by the atmosphere, and the melted fluxes and coatings and products of oxidation in contact with the fluid metal.

(1) Atmospheric action is preponderant or exclusive in gas-welding without flux, and in naked arc welding; there is at once absorption of gas and loss of oxidizable elements; just as in steel-making in the converter, nitrogen[1] and oxygen are absorbed, and silicon, carbon and manganese are eliminated.

(2) The action of fluxes and coatings resists that of the atmosphere, notably in connection with the absorption of nitrogen,[1] and there is chemical exchange between the two melted phases—metallic and non-metallic—as happens between the fluid metal and the slag in an open-hearth furnace.

Although the laws of physical chemistry permit the anticipation of the direction of chemical changes, it is not possible on the other hand to predict the extent or magnitude of the resulting chemical modifications, in view of the complexity of the phenomena—to which may be added the temperature uncertainty and extremely restricted time of the operations. Experience only can provide the data, and very little information has been published on the subject.

An investigation has therefore been undertaken with the object of acquiring data concerning these chemical modifications. In this paper it is proposed merely to set forth some preliminary results relative to the variation of the essential elements carbon, silicon and manganese, in the gas-welding of steel containing only these elements (apart from the impurities sulphur, phosphorus, oxygen and nitrogen).

Particular attention is drawn to the fact that everything influencing the time and temperature of the operation, the composition, mixing and flow of the hot gases, the extent and time of contact of gas with melted metal, can play their part in the chemical changes, quite apart from the chemical composition of the metal to be welded and the weld-metal; such factors are the size of the flame, its control, the method of welding, the size of the weld, the diameter of the weld-metal rod, the thermal properties of the metal, etc., each of which has its separate bearing on the result.

The question, therefore, is not simply one of determining the order of magnitude of chemical modifications under certain clearly defined conditions. Taking into consideration only the case of a carefully controlled oxyacetylene flame regulated as in accepted welding practice, chemical analyses have been made on metal strips and beads deposited upon cold thick steel plates, and upon surface welds on chamfered steel plate 10 mm. thick, using a weld-metal identical in composition with the parent metal. Later on the first results of these tests are given, made upon steels with contents varying from

0 to 1.0 per cent carbon.
0 to 2.0 per cent silicon.
0 to 2.0 per cent manganese.

The sulphur and phosphorus contents were very small, less than 0.02 per cent.

The preparation of samples for analysis was made by drilling after carefully cleaning the surfaces. In the case of the metal beads the turnings were taken in bulk in order to obtain an average sample. For the 10-mm. plate weld, the welding run was sampled by drilling a hole about the symmetrical axis of the weld, using a 10-mm. drill for a depth of 2.5 mm., followed by an 8-mm. drill for a depth of 2.5 mm., and finally a 6-mm. drill for a depth of 3.0 mm., in order to arrive at an average sample. (See Fig. 1.)

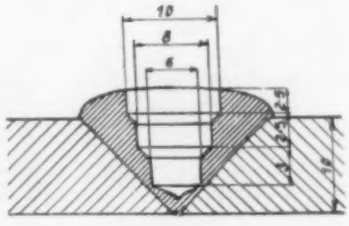


Fig. 1

The different steels examined have been chosen from among those most commonly used in welding operations; some others of high manganese and silicon contents have been added in order to determine from the results obtained the direction to be given to future experiments. The series of samples dealt with is not therefore systematic but discloses gaps. For this reason, and also in consequence of the stated irregularities, representative

* Presented before Symposium on the Welding of Iron and Steel, May 2 and 3, 1935, London.
† École Supérieure de Soudure, France.
[1] See A. Portevin and D Séférian, contribution to the present Symposium.

Fig. 2

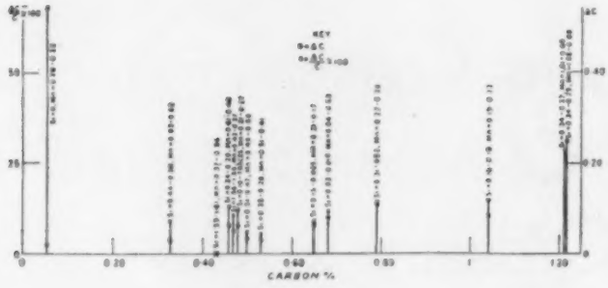
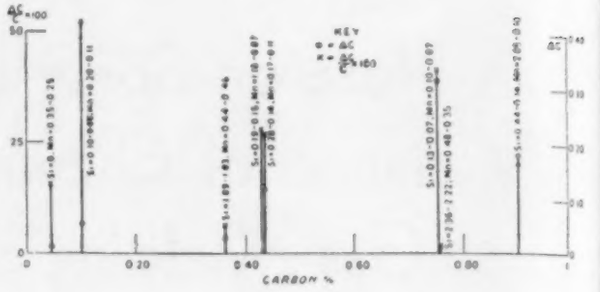


Fig. 3



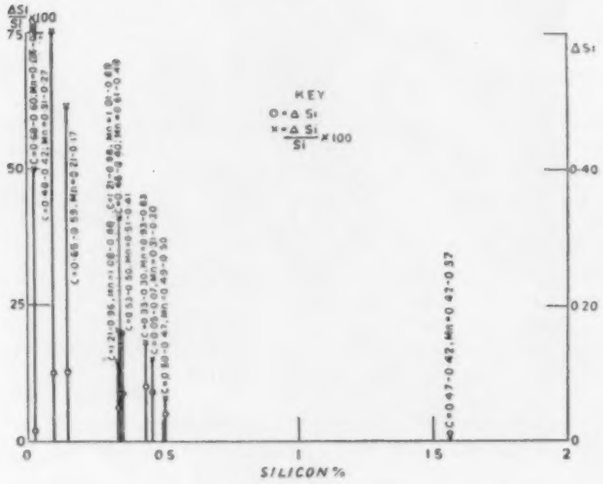


Fig. 4

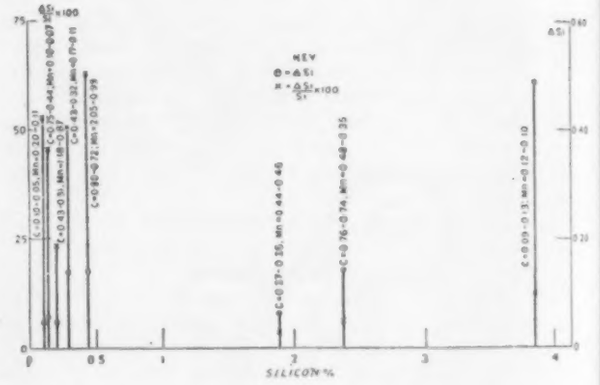


Fig. 5

curves of each of the three elements considered, carbon, silicon, manganese, cannot be drawn. On the other hand, tables being tedious to read and frequently lacking in clarity, we have adopted graphical representation, from which the results can be seen almost at a glance.

We have therefore marked as abscissæ the initial contents of carbon, manganese and silicon. Although the plates and the welding rod are from the same cast of steel there are slight differences between them in chemical analysis; in the case of the weld the mean results have been taken as the initial content.

Ordinates of the curve have been marked as differences found between the initial contents and the contents in the bead metal or the weld metal, thus ΔC, ΔMn, ΔSi. The relative differences in relation to the initial contents are also set forth thus:

$$\frac{\Delta C\ 100}{C}, \quad \frac{\Delta Mn\ 100}{Mn}, \quad \frac{\Delta Si\ 100}{Si}.$$

Near each representative point the initial and final contents of elements other than those represented in the graph are noted.

Generally speaking, for the low contents of these three elements the differences found are often of the same order as the errors in analysis; however, it is undesirable to attach too much importance to the indicated results, particularly to those of the relative initial contents which in themselves are subject to the same uncertainty of determination. In addition, in the case of carbon, the effects of carburization resulting from a slight accidental variation of the flame have to be taken into account.

Subject to these reservations the following remarks about the graphs may be made.

Carbon

Simple beads of metal (see Fig. 2). With the usual manganese and silicon contents the loss in carbon (ΔC) varies little; it fluctuates round about 0.1 per cent in absolute value (consequently the relative loss $\Delta C/C$ decreases when the carbon increases).

In the welds (see Fig. 3) this mean loss, ΔC, is higher and appears to increase with the carbon content; this is attributable perhaps to the welding requiring a longer period of heating of the melted metal, resulting in a more severe surface decarburization, which is all the more marked the higher the carbon content of the steel.

An increase in manganese content up to 1 or 2 per cent does not appear to have any definite action.

On the other hand, increases in silicon content, of the order of 1.5 to 2.5 per cent silicon, greatly lower the carbon loss. No doubt for this reason carbon losses are relatively low for cast irons in which a high carbon content is accompanied by a high silicon content.

Silicon

With the fused beads of metal (Fig. 4) the loss in silicon, ΔSi, appears on the whole higher for the low contents ($Si \leqslant 0.5$ per cent) than for high contents (Si = 1.5 to 2 per cent). This is explained, in the latter case, by the formation of a protective silica film, and also by the fact that the rapid solidification entraps the silica, which is also included in the chemical analysis, as silicon.

By melting a high-silicon steel and agitating it with an oxidizing flame it has been possible to obtain a loss of silicon of 0.3 per cent (thus $\Delta Si/Si = 7$ per cent); an estimation of the silica by volatilization in chlorine

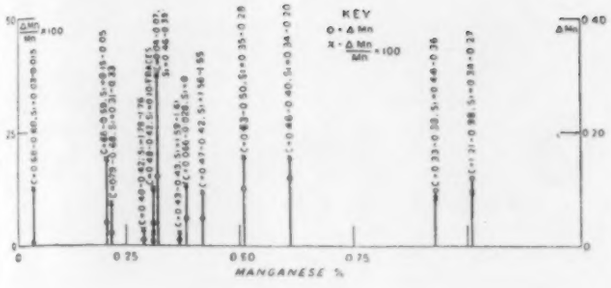


Fig. 6.

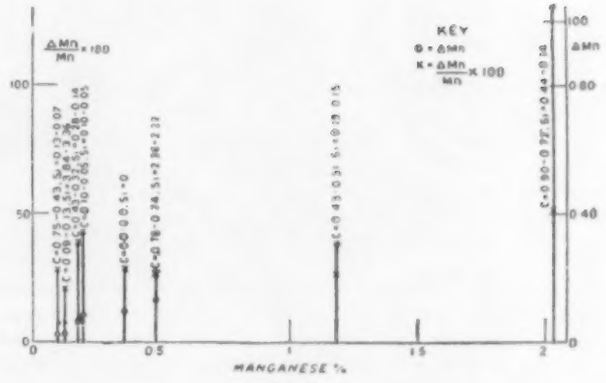


Fig. 7.

showed none; in this case, then, owing to the prolonged fusion, the silica formed was expelled.

In the welds (Fig. 5) the losses (ΔSi) are variable for low contents, but increase sharply in absolute value with the silicon content when this is above 1.5 per cent.

With cast irons, owing to the lower melting point, the iron oxide formed does not melt and recourse is necessary to an alkaline carbonate base; these oxygen-bearing alkaline salts oxidize the silicon and greater losses in ΔSi are noticed, from 0.2 to 0.4 per cent for the 3 per cent silicon contents (the usual silicon content for weld-metal rod used for welding cast irons).

The part played by silicon (and also by aluminium) in forming a protective coating resisting the loss of oxidizable or volatile elements when the melt is fluid is general; it can be observed and turned to use not only for steels but also for other alloys, such as those of copper.

Manganese

With the fused strips of metal (Fig. 6) the loss, ΔMn, tends to increase with the manganese content up to about 0.1 per cent, around which figure it fluctuates when the manganese content varies between 0.5 and 1 per cent. In the welds (Fig. 7), on the contrary, the loss (ΔMn) varies with the manganese content.

Conclusions

It should be understood that the results stated are only the first obtained during the preliminary investigation made for the purpose of directing an intended subsequent series of more complete observations. The few indications the authors have thought it useful to outline must be considered provisory, and it is solely because sufficient data had not been found in published technical literature that it was decided to make these results known at once.

Considering these results as a whole, it is demonstrated that silica serves a protective purpose against carbon losses by oxidation during fusion and gas-welding of steel; but it does not appear to have any marked influence on manganese losses, and this latter does not seem to have any effect on carbon losses for the amounts of these two elements usually present.

Attention is drawn to the differences in chemical variation noticed for these same steels between the simple fusion of a weld-metal rod forming the ribbon or bead and the actual weld. The different periods of time and conditions of fusion and oxidation entail variable losses in carbon, silicon and manganese, not only in absolute value, but in relation to the chemical composition of the steel; no definite inference can therefore be drawn, from the point of view of chemical composition, as to the relation between the metal bead and the weld made with the same metal.

Electro Fusion

By C. J. HOLSLAG†

THE derivation of the name "ARC" comes from the mathematical Greek arc of a circle and the engineering, again Greek, Arch. In other words, the name "ARC" came from the first observers noticing the fact that with the direct current as a source of supply the arc bowed outward in an effort to extinguish itself. This is caused by the magnetic flux which follows the circular theoretical path of the current around the wire, even that part which jumps the gap making the arc because of the direct electro-magnetic mechanical influence to push it to one side. Perhaps you have noticed especially with heavy current the welding or ground leads jump or writhe when the arc is started or stopped. This will show the layman the existence of the electro mechanical force due to the magnetic current through the wire. This force exerted on the current that jumps the gap bends this circuit outward into the arc of a circle. If there is not enough voltage or reactance or tenacity to the arc this force will cause it to break. It is this same force which causes the arc to wander and not stay in one position. That is, it bends out and seeks new paths and is very unstable, as can be noticed with a long arc or a long carbon arc. Furthermore, when this D.C. arc comes to the edge of a plate or to a corner or to any condition where the magnetic influence changes in quality or direction, the arc assumes new positions and very often squawks and protests and tries in every way not to follow a path which is generally the one desired. You see this action noticeably at the edge of a plate or in a corner especially when working on iron as magnetic conditions change so materially that it is hard to guide the arc along the path desired. Even the position of the ground or the direction from which the current comes to or leaves the arc determines this bowing effect. Of course this phenomenon is used in circuit breakers and other apparatus possessing blow-out coils to extinguish the arc but in arc welding the idea is not to have it extinguished, not to have it bend and twist and struggle against following the path desired. In a fuse also this action ejects the

† Electric Arc Cutting and Welding Company.

molten particles so as to break the circuit and in many fuse boxes blow-outs are used to aid in extinguishing the arc.

Now with alternating current conditions are different. There is no bow and the word "ARC" is not applicable. If the reader is acquainted with the wire straightening machine he will have noticed that the machine consists of a great many rolls or pegs which strike the wire at a great many different angles so the net result is that the wire has no permanent set in any direction but becomes straightened. The explanation of this is the wire is bent in so many directions, so fast, that the net result is zero and the wire comes out perfectly straight. So with alternating current on 60 cycles, the arc is influenced 120 times a second in reverse directions. Even on 25 cycles the reversal is fifty times per second. The net result is that any A.C. arc is directed straight and directly out from the tip of the electrode, whether to another electrode, to a plate or under any condition. This straightness or lack of magnetic blow and evenness of the inductive reaction allows you to go to the end of a plate, down to the end of a corner or to any position without the arc struggling to assume some other path. This phenomena of arc is shown by the fact with a twenty-four inch carbon a blow-hole can be burned out in a casting even though the carbon touches the sides of the hole as it progresses. The arc will stay out at the end like water from the hose of a nozzle. There is no way to direct a D.C. arc with additional magnetic field as it only makes it worse. About twenty years ago I made coils to weld overhead. The A.C. arc is self-correcting as explained and if it should be pushed aside by magnetic action it will remain in that position and not twist and turn. This is used in the bent out Hydrogen Gas Arc, a true arc which can be used only with A.C. Furthermore, the inductive kick or magnetic flux reaction from an A.C. arc is definite and steady and at 500 or 600 amperes sufficient to take the weight of the electrode and its holder so the operator is not inconvenienced or fatigued. With the D.C. arc and heavy current it is a considerable struggle to hold the electrode itself in a direct line.

The point of this article is to provide a name for this new A.C. arc which is not an arc. If the A.C. arc had been invented first it would never have received the name "ARC." It might have received the name "Concentrated Directed Energy" or equivalent.

It is the advantages of the metallic arc that have allowed arc welding to assume such prominence in industry.

The word I would like to suggest for this A.C. arc is "The Fusion of Electrodes" or to shorten it to "Electrode Fusion" or shorter yet, "Electro Fusion." As long as A.C. does not arc, let us call it something—I propose "Electro Fusion."

Looking through Welds

By M. B. ADRIAN†

MANUFACTURERS can now "see through" their products on the production line and detect flaws or stray pieces of foreign materials.

As products pass through the machine on a conveyor belt, the operator looks through an eyepiece to get an interior view of each unit. Any unit which does not come up to requirements can be marked for rejection by means of a pointer device.

This is the first time it has been possible to make an X-ray inspection fluoroscopically of goods in motion on the production line. The machine also has a radiograph attachment for making X-ray photographs, in case these are desired of any specific product.

Aluminum castings are examined for flaws in the metal, mica or bakelite is inspected for metal objects which might interfere with its efficiency as insulation, slate for rust spots, asbestos shingles for cracks, porcelain for cracks, and so on. Fluoroscopic work has been done through one-fourth inch of plate steel, and radiographing with one inch of steel.

Although it has a voltage capacity of 150,000 volts, the unit requires only about the same amount of current necessary to operate two ordinary flat irons. Special tubes have been constructed and a cooling arrangement devised which permit continuous operation of the ma-

† Adrian X-Ray Manufacturing Company.

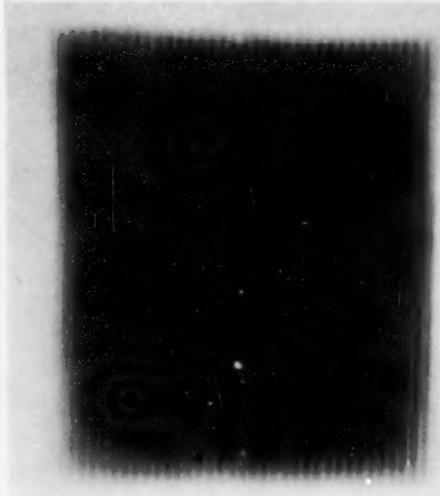


Fig. 1.

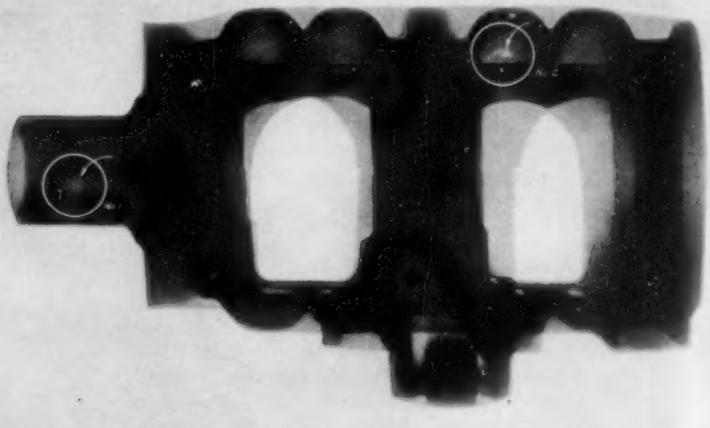


Fig. 2.

chine during working hours. No technical knowledge is required by the operator, who is in no way exposed to rays of the machine.

Figure 1 is a reproduction of an X-ray negative taken on our unit showing a defective weld on a piece of $^1/_2$-in. sheet steel. In taking this photograph we used a grid which accounts for the lines on the picture. The evidence of this bad weld was not visible to the eye. After cutting into the steel we found the condition that the picture shows. This photograph was taken at 150,000 volts, 7 M.A. and an exposure of ten seconds.

Figure 2 is a reproduction of an aluminum casting. The condition of this casting was discovered fluoroscopically. Note the weak spots in this casting. The company from which we received this casting was having considerable trouble with leaks which reduced the compression of the engine. Their water test was not satisfactory as a very small seal of metal would prevent the water from breaking out. Using the X-ray for their inspection gave them the advantage of finding out a bad condition before there was any labor spent on the job and this meant a large saving to their company. There is no question but what this casting could be repaired by a welding process.

Welding Refrigerators

By W. H. GIBB†

THE paradox of why seam welders are used to make spot welds is easy to explain. The parts produced are evaporators for refrigerators. They are made up of two sheets of metal with hollows or flutes pressed into the surface to form evaporating chambers. While

Fig. 1—Here Are 8 of the Welders Installed in the G-E Schenectady Works. Each machine makes 300 spots per minute

the outer edges of the two halves are joined by a pressure tight seam weld, the job requires only closely spaced spot welds between the chambers. In this case, the welds could be made better and faster by intermittent

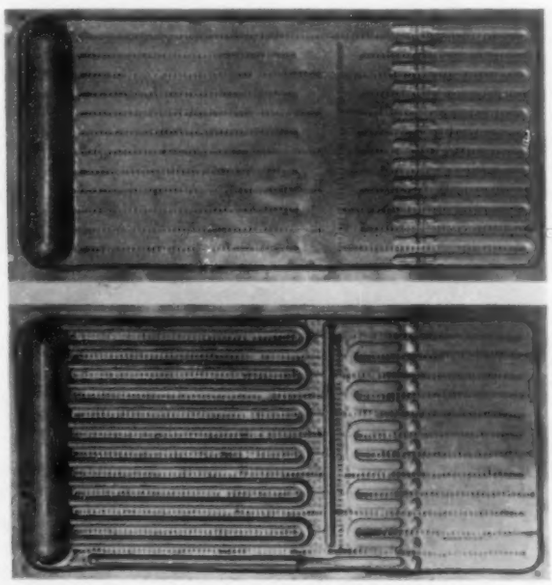


Fig. 2—Back and Front Views of the Refrigerator Evaporator Showing Both Pressure-Tight Seam Welds and Intermittent Seam Welds on the Same Part

seam welding on the same seam welder, than by spot welding on a regular spot welding press. Intermittent seam welds are made by applying the current in short cycles in relation to the speed of the welding rolls.

Another unusual feature of these seam welders is the design of the welding roll. As you can see in the picture of the evaporator parts, the welds must start close against an obstruction on either end of the shell. By cutting out a small segment of both the upper and lower rolls, a way was provided to fit the parts between the rolls and start the weld flush against the obstruction. Because the design of the evaporator calls for seams of varying length, it is not possible to make these welds in one continuous operation. It takes only a little longer, however, for the operator to start the weld at one end, run it half way down the piece and then turn the work end for end and start another weld which meets in the center. To make this as efficient as possible, the welding rolls are fitted with an arrangement of counter weights that bring the segments back into starting position as soon as the foot valve which operates the machine is released.

It is interesting to know that this work was done originally on spot welders at the rate of 150 spots per minute. The new seam welders turn it out at double that speed.

† Vice-President, Thomson-Gibb Electric Welding Company.

Welding in the Aeronautical Industry*

By J. B. JOHNSON, M.E.†

WELDING plays an important and valuable rôle in the manufacture of American aircraft. It received its first impetus from the success attained by A. H. G. Fokker in Holland in the oxyacetylene welding of fuselages. Improvements in his designs and the application of alloy steels were introduced by several aeroplane builders. These have been described in detail in the publications listed at the end of this paper, and only a résumé will be given.

Welding is used successfully for fuselages, control surfaces, landing gears, wing beams, exhaust manifolds, tanks and fittings for all types of aeroplanes from the small sport models to the large transports and bombers (Figs. 2 and 3, Plate I). The original structural material was a straight 0.25 per cent carbon steel. This did not satisfy the requirements of military aircraft for high load factors, and a chromium-molybdenum steel was developed (see Table I), which is now used almost exclusively wherever steel is used for the main structural parts. It has air-hardening properties which counteract the softening effect due to the heat conducted into the base-metal near the fused zone. It may be used in either the normalized condition or heat-treated by quenching and tempering to obtain a wide range of mechanical properties. An allowable unit stress in tension of 80,000 lb. per sq. in. for the material adjacent to the welded zone has been standard practice for several years. The value for carbon steel is 45,000 lb. per sq. in. In the case of joints heat-treated after welding, a stress equal to 80 per cent of the tensile strength of the heat-treated base-metal is allowed, with an additional proviso that the unit stress in the deposited metal shall not exceed 50,000 lb. per sq. in.

Several materials used for welded non-structural parts are given in Table 1. Annealed corrosion-resistant steel is used for exhaust stacks, manifolds and mufflers. It retains its strength at elevated temperatures and resists corrosion from the products of combustion of aircraft engines using petrol containing tetra-ethyl lead. Titanium is used to prevent embrittlement which may occur during continuous exposure at the operating temperatures. Before titanium was used brittleness was found in short stacks in the base-metal adjacent to the welded seam after a period of from two to three hundred hours in service. This steel welds readily. Coating both sides of the seams with a flux facilitates oxyacetylene welding, and a coated electrode is always used for electric arc-welding. Welding strains are relieved by heating to 1600° F. and cooling in air.

Nickel alloy, Inconel, is also used for parts operating at elevated temperatures. It is easier to fabricate than corrosion-resistant steel and possesses good weldability. No embrittlement of this alloy has been experienced.

Aluminum and aluminium alloy (1.5 per cent manganese) are used for fuel, oil and water tanks, cowling and miscellaneous parts. The castings used for flanges, filler neck and similar parts welded to tanks are generally made from the 5 per cent silicon, 95 per cent aluminium alloy. The alloys which are hardened by heat treatment are not welded except in very special cases where the strength in the welded zone is unimportant. Pure aluminium welding rod has proved most satisfactory for welding aluminium, and a 5 per cent silicon rod for welding castings and the manganese-aluminium alloy. The fluxes used are mixtures of sodium, potassium and lithium chlorides, with or without additions of sodium and potassium fluorides.

Magnesium alloys are used for tanks, seats and other non-structural parts. Welding rôd of the same material as the base metal is used and a flux similar in composition to that used for aluminium. At present their field is rather limited owing to the corrodibility of the metal in saline atmospheres.

The methods of welding which have been used extensively enough to be called production processes are:

(*a*) Gas-welding.
  (1) Oxyacetylene.
  (2) Oxy-hydrogen.

* Presented before Symposium on the Welding of Iron and Steel, May 2nd and 3rd, London.

† War Department Air Corps, Wright Field, Dayton, Ohio, U. S. A.

Table 1—Materials for Welded Aeroplane Parts

Classification	Chemical Composition						Tensile Strengths, Lb. per Sq. In.	
	Carbon, %	Nickel, %	Chromium, %	Manganese, %	Molybdenum, %	Iron, %	Before Welding	After Welding (Oxyacetylene Butt-Weld)
Plain carbon	0.20[1]	..	..	0.50	..	99.0	55,000	45,000
Chromium-molybdenum	0.30	..	1.0	0.50	0.20	98.0	90,000	80,000
Corrosion-resistant	0.07[2]	18.0	8.0	0.50	Ti[3]	70.0	80,000	80,000
Inconel	0.15[2]	75.0	10.0	1.25	..	9.0	80,000	70,000
Aluminium	Aluminium, 99 per cent						16,000	12,000
Aluminium alloy	Aluminium, 98		Manganese, 1.5 per cent				19,500	14,000
Magnesium alloy	Magnesium, 95		Aluminium, 4		Manganese, 0.3 per cent		32,000	15,000

[1] Minimum value in specification.
[2] Maximum.
[3] Titanium not less than 5.5 × carbon content.

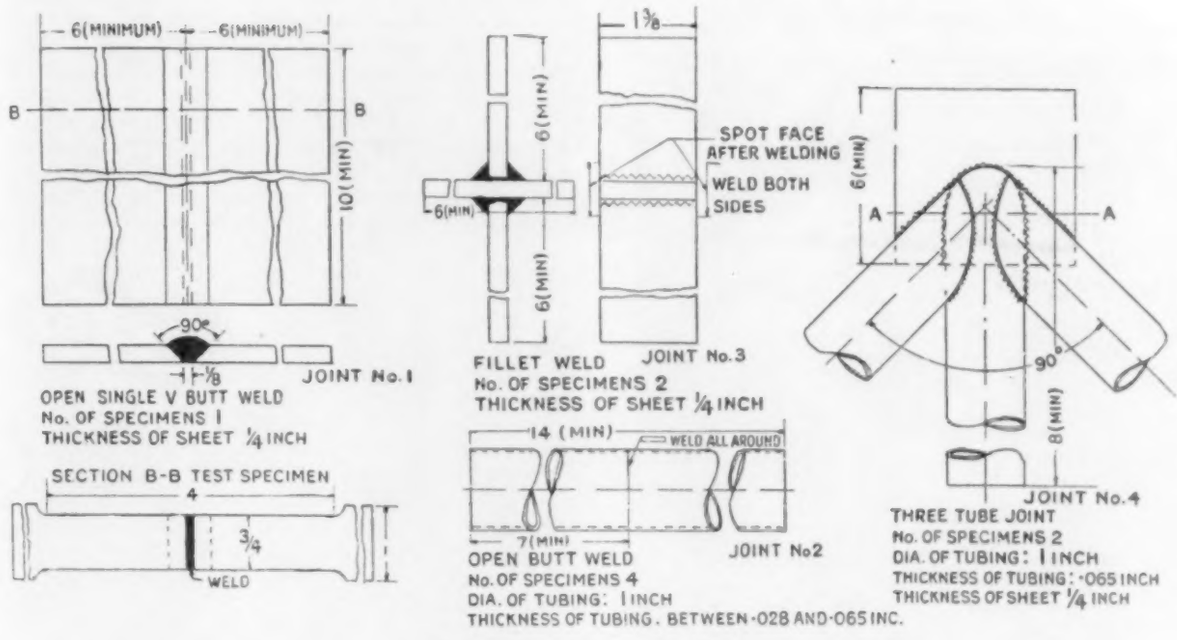


Fig. 1—Qualification Test for Aircraft Welders

(*b*) Direct current electric arc-welding.
(*c*) Electric resistance welding.
(1) Flash-welding.
(2) Spot-welding.
(*d*) Atomic hydrogen welding.

Oxyacetylene welding is applied much more than any of the other types. It is used for welding all parts, and in most aeroplane factories is the only process available. The equipment is very flexible and relatively inexpensive, and it is possible to train welders in a period of from three to six months, depending upon the aptitude of the individual and the character of the work. Low-carbon welding rod has been used for both the carbon and the chromium-molybdenum steel, although a chromium-molybdenum steel containing $3^1/_2$ per cent nickel, and a 60/40 brass containing a small amount of silicon have had limited application.

Oxy-hydrogen welding is used as an alternative to oxyacetylene welding for aluminium and magnesium and their alloys. A comparison of the serviceability of aluminium tanks fabricated by these two methods of welding indicates that neither is superior to the other, and the selection of the process to be used is largely a matter of individual preference.

Direct current arc-welding is used for joining carbon and alloy steels but not for non-ferrous metals. Alternating current arc-welding was tried but never developed to give as reliable results with thin metal sections as the D.C. process. The D.C. metallic-arc process is used for ferrous metal parts similar to those welded with the oxyacetylene flame, but is not quite as adaptable as the latter for small fittings made on the bench. The lack of proficient welders has been an obstacle to its extensive use. Operators require a longer training period and fewer are able to qualify.

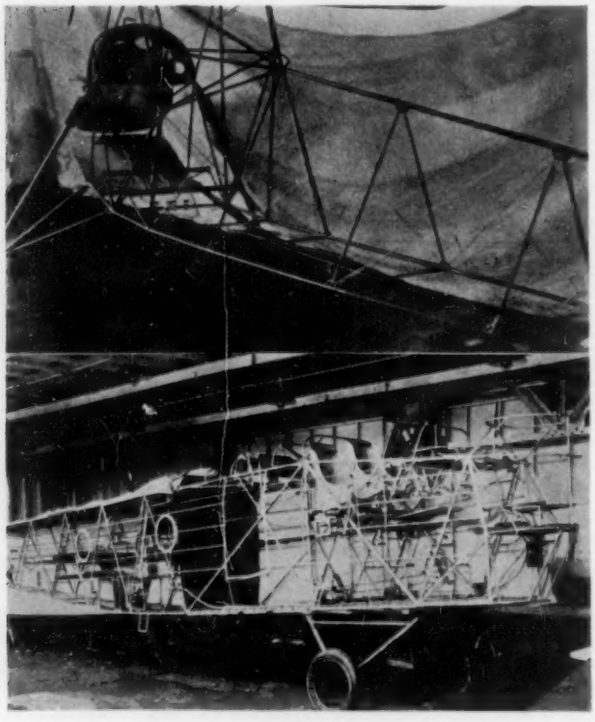
Flash-welding has been used for joining two straight pieces of tubing and applying solid fittings to the end of a tube. It requires expensive shop equipment and set-up, and until aeroplanes are made in much larger quantities, it is not likely to become important. The finished weld has an excellent microstructure, as the grain-size and composition are changed very little from those of the base metal. A flash-welded joint has the highest fatigue resistance of any type with which the author is familiar.

Spot-welding is used for joining corrosion-resistant steel (18 per cent chromium, 8 per cent nickel) and aluminium and aluminium alloys. It has the advantage over other processes of greater speed and minimum effect on the base-metal. Severely cold-worked metal can be welded with less distortion. The present production of spot-welded aeroplane parts in the United States is relatively small, but several experimental structures have been fabricated and design data are being accumulated. A large number of smaller assemblies, such as ribs, ammunition chutes and other low-stressed parts, are manufactured by spot-welding. Similar parts have been made from aluminium alloys. The present trend in aircraft construction is toward an all-metal monoplane with a monocoque fuselage and an internally braced wing. This type of structure offers great possibilities for the application of spot-welding and undoubtedly there will be intensive development in the field.

Atomic-hydrogen welding was investigated as a process for general application to the welding of aeroplane structures, but was never used as a production process on account of the bulkiness of the equipment, which made it difficult to weld in restricted places. It has found a field in the manufacture of welded steel propellers. This is one of the most exacting applications of welding, and the high ductility of a welded seam deposited by the atomic-hydrogen flame is an advantage. A propeller is constructed of two sheets of chromium-vanadium steel, tapered, formed and welded together at the edge. The welded structure is heat-treated to yield a tensile strength of approximately 135,000 lb. per sq. in.

Welded seams contain blowholes and sharp corners due to change of section, and these tend to cause stress concentration and lower the fatigue resistance. A great deal of effort has been expended in perfecting a welded seam in the propeller blade which is practically free from these defects. A rigid magnetic inspection is carried out at several stages of manufacture. The blade is

Fig. 2.—Fuselage of 900-lb. Aeroplane



(Plate 1)

Fig. 3—Fuselage of 14,000 lb. Aeroplane

placed in a strong magnetic field, and fine, rounded iron filings (Magnaflux powder) are distributed over the surface. The powder piles up in a characteristic pattern wherever there is a crack, blowhole or any defect which forms a discontinuity in the magnetic field. By this means it is possible to obtain a blade which has been rigorously tested. There are now over 1000 of these blades in service, several of which have given more than 1800 hours' flying time.

The large structures are used as welded. Smaller structures such as engine mounts and control surfaces are sometimes normalized by heating above the critical temperature, and cooling in air in order to relieve welding strains. Many individual assemblies such as spars, struts, axles and fittings are welded and then heat-treated. Wing spars, fuselage sections forward of the cockpit, and many assembled fittings are treated after welding to yield a minimum tensile strength of 150,000 lb. per sq. in. Spars up to 20 ft. in length, heat-treated as a single welding assembly, have been used in several production aeroplanes. Landing-gear struts, tail wheel supports and axles are generally heat-treated to give a minimum strength of 180,000 lb. per sq. in. These parts have proved entirely satisfactory in service.

The uniformity of welding is controlled by examining each welder for proficiency at stated intervals. This procedure includes a qualification test which requires the manufacture of several joints. These joints are indicated in Fig. 1. The number of joints which a welder is required to make will depend upon his experience. In the case of joint No. 1, tensile specimens are cut with the weld in the middle of the specimen, and it is required that the average strength shall not be less than 45,000 lb. per sq. in. where the base-metal is plain carbon steel, and 70,000 lb. per sq. in. for alloy steel. The weakest specimen should not be more than 10 per cent below these values.

In the case of joint No. 2, one set is welded on the bench and a similar set in an overhead position not lower than the welder's eyes. The joints are tested as tensile specimens and the required breaking stress if 50,000 lb. per sq. in. for plain carbon steel and 80,000 lb. per sq. in. for alloy steel calculated on the base-metal.

Joint No. 3 is also tested in tension, and the joint is required to develop not less than 10,000 lb. per lineal inch where the base-metal is plain carbon steel and 15,000 lb. per lineal in. for alloy steel. Broken test specimens must indicate intimate fusion between the base-metal and the filler rod.

Joint No. 4 has proved to be very satisfactory for improving the quality of welding. This is a composite joint made from sheet and tube, and requires welding of parts of different thickness, as well as welds over previous welds. The joint is pulled in tension and shall develop not less than 1500 lb. per lineal in. for plain carbon steel and 2500 lb. per lineal in. for alloy steel. After the tensile test the specimen is cut at section *A-A*, polished and etched with 50 per cent aqueous hydrochloric acid. A visual examination of the section indicates the amount of penetration at the weld. The etched specimen is

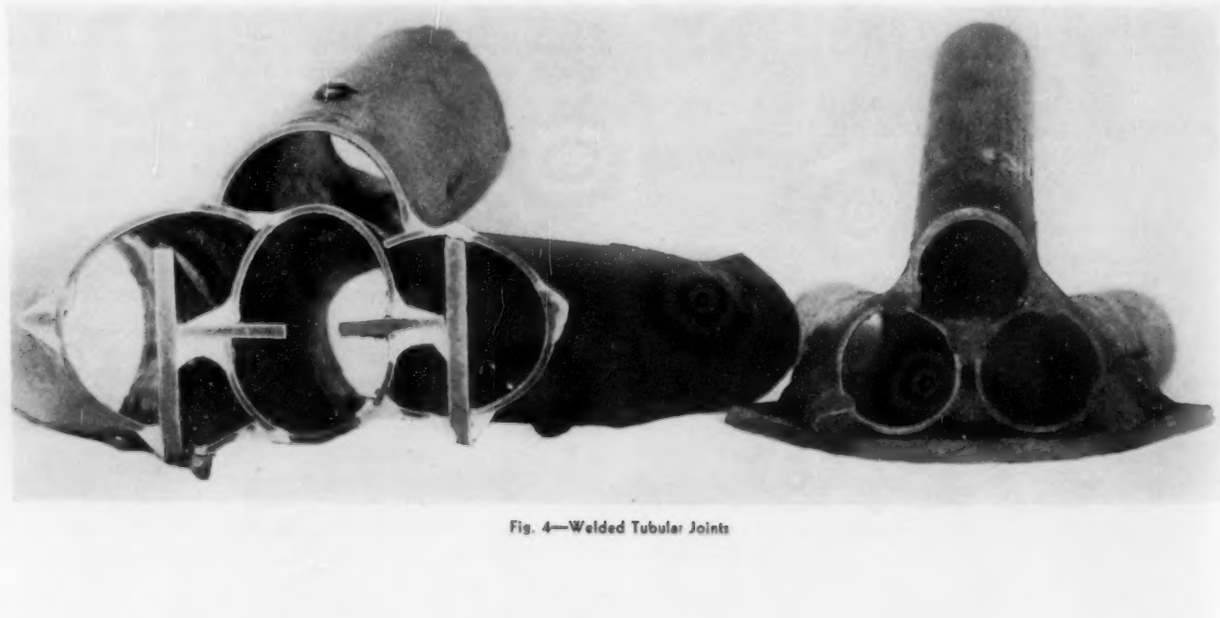


Fig. 4—Welded Tubular Joints

Fig. 5A.

Fig. 5B.

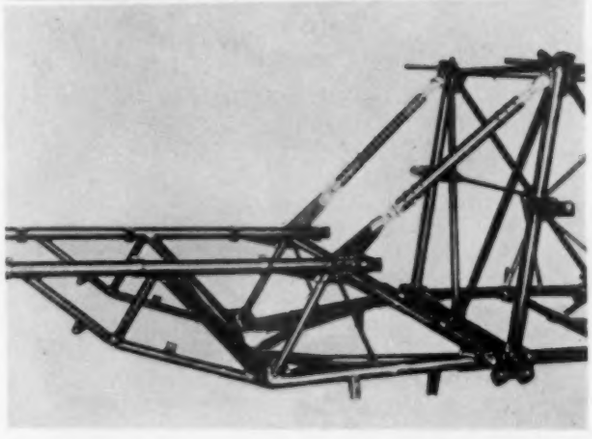


Fig. 5—Engine Mountings

shown to the welder so that he can correct any defects in his welding. An aeroplane fitting with the characteristics of joint No. 4 may be substituted, and a sample selected at random from a lot by the inspector. Cross sections through two joints are shown in Fig. 4. (Plate II.) The joint on the right was welded with the D.C. arc, and the one on the left with the oxyacetylene flame. Complete penetration is a characteristic of the former. When this does not occur the bead would be considered unsatisfactory. The oxyacetylene weld should indicate a fused area with a well-rounded base fused into the metal under the bead. Several welds in this fitting do not show this, and the joint would not be considered satisfactory.

Failures in welded parts may be attributed to: (*a*) Design; (*b*) material and (*c*) workmanship. Those due to design have rapidly decreased with the experience gained by aeronautical engineers. The majority of such failures were in engine mounts. The common faults were inadequate gussets, causing concentration of stresses at the edge of the welded seam; long column members resulting from insufficient trussing, permitting vibrations of large amplitude; and bolts for detachable units too small, with resultant wear and excessive vibration, all of which led to fatigue failures. The correction for these is obvious, and it is now possible to check a design with almost complete assurance that it will not fail in service.

The failures due to materials are very infrequent, but there have been cases in which the base-metal cracked during welding without any apparent contributing factor. Such failures are confined to chromium-molybdenum steel, and generally to tubular members. It has been the author's experience that only an occasional piece of steel from a heat is so affected, and that the microstructure and chemical composition are normal. Heating the steel just above or below the critical temperature and cooling in air before welding will correct the condition. This cracking may be caused by internal stresses which are added to those normally caused by contraction during welding, so that the total stress reaches a value which ruptures the metal. Cracking of this type can almost always be detected by the welder, or later by the inspector.

Workmanship is the most prolific cause of failure. This includes not only failures due to carelessness or lack of experience on the part of the operator, but also those chargeable to defective or inadequate welding equipment, jigs and fixtures, and improper preparation of the work to be welded. Welding foremen have had to learn that jigs must not place any tension or bending loads on a joint being welded; in fact, a small compression load which will not buckle the hot metal may assist in preventing cracks due to contraction and expansion of the base-metal. The laws governing the application and flow of heat must be understood in a practical way, so that the weld will be started at the right place and heavy sections will be preheated so that they will not pull away from lighter sections. It should be further realized that steel quenched and tempered to develop high tensile properties must not be heated too rapidly.

The factor which has given rise to the most criticism is the lack of adequate inspection. Although it is a fact that the visual inspection of the outside of a welded joint cannot be depended upon to give positive assurance that the weld is satisfactory, it has been the only method used on thousands of joints which have withstood the most rigorous service test. The welded joint is essentially a rigid joint without wearing parts, and if properly protected from corrosion there is no deterioration. Many joints cut from structures which have been in service for five to eight years have indicated that the original strength is not impaired. Magnetic inspection and X-ray inspection of welds have been used and for some types of work are very satisfactory. Neither of these methods has been applied in general to the inspection of such structures as fuselages and control surfaces. Magnetic inspection has proved more satisfactory than X-ray inspection, as the defects are generally very small and the technique used in making the radiograph must be very exact in order to register the presence of the defect on the film. The X-ray beam must be applied at several different angles, which is very expensive and time consuming.

Welded steel construction reached a peak in 1931 and 1932 when over 75 per cent of the aeroplanes manufactured in the United States had welded steel fuselages. Since that date monocoque designs employing a stressed skin of aluminium alloy have been developed and are replacing the welded fuselage. Thick cantilever, monoplane wings with a stressed skin and multi-spar or box construction favor the use of aluminium alloys or cor-

rosion-resistant steel rather than built-up spars of heat-treated alloy steels. The applications of oxyacetylene and arc-welding will probably continue to decrease except for engine mounts (such as are depicted in Figs. 5a and 5b, Plate III) and landing gears and miscellaneous fittings. Resistance spot-welding offers advantages in the new type of construction, and with the accumulation of design data and manufacturing technique the completely welded structures may again dominate the field in aeroplane construction.

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Metallurgical Fundamentals of High-Speed, High-Quality Autogenous Welding*

By A. B. KINZEL†

ALTHOUGH welding has been in commercial use for more than two decades, only in recent years has it been given the serious attention of the metallurgists. A logical approach, from the metallurgist's view-point indicates at once that there are three fundamental requirements for any type of weld: First, mechanical homogeneity of the joint, frequently termed "complete fusion"; second, resulting deposited metal and adjacent base metal of high strength and ductility; third, freedom from internal stress of a high order of magnitude in the finished welded assembly. In the following, an attempt will be made to analyze and discuss these fundamental requirements in so far as autogenous welding is concerned.

The first fundamental principle involved in fusion welding implies that the surface of the material to be joined shall form a liquid solution with the molten metal, generally added from a welding rod and used to fill the space between the pieces to be joined. It should be specifically noted that a continuous liquid solution is called for, and that this does not necessarily mean complete liquefaction of the surface of the materials to be joined. In practice, and for many years, however, such complete melting of the edges to be joined was a distinct and important part of all fusion-welding processes, and lack of cohesion between the deposited metal and the base metal was considered to be caused by failure to fuse the base metal. However, as is well known to metallurgists, low carbon iron or steel has a definite melting or fusing temperature range, the boundaries of which are known as the liquidus and solidus. Consider the joining of plates by butt-welding. If the plate is completely fused to a given depth from the original surface, the fused material from the plate forms a liquid solution with the fused material from the rod, but the actual junction between the plate and what is later considered to be weld-metal takes place at that surface at which the material is between the solidus and liquidus temperatures, and rather nearer to the solidus. Thus, there would seem to be no virtue in melting an appreciable portion of the plate material, as this plays no rôle other than that of the added welding-rod metal. It has also been deemed necessary to melt the base metal in order to ensure that the junction surface in the liquidus-solidus temperature range shall be free from foreign matter. Such foreign matter may be present as direct iron oxide film or inclusions originally in the steel or formed during heating.

From the above it is evident that, provided a means can be found to ensure the presence of the desired junction surface free from foreign matter, there is no necessity for melting the base metal. This brings us to the first principle involved in the development of high-speed, high-quality autogenous welding, namely, the production of a clean junction surface on the base metal with minimum or even negligible melting of the base metal proper during the operation.

In a given welded joint, the amount of heat that can be applied is generally subject to limitations. In gas welding these limitations are caused by the physical location of the torch or torches and the limited space in which to apply such torches. In electric welding the limitations are due to difficulties in controlling the arc at high current densities.

The physical and geometric limitations involved in

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gas welding may be overcome by a proper attack of the problem, separating the welding process as a whole into two distinct but coordinated operations: First, preparing the junction surface as indicated above, and second, adding molten welding-rod metal at the proper rate. Based on this point of view, a number of developments have recently been made which have markedly improved the speed of welding, and these may be broadly grouped under three headings:

(1) The use of preheating flames on the plate and scarf.

(2) The use of a carburizing flame in connection with the preparation of the scarf.

(3) The proper position and motion of the heating and preheating flames with respect to the added metal. These are the bases for the development of gas welding technique. While the position of the melting flames and the selection of preheating flames require no special explanation and may be considered as mechanical rather than metallurgical developments, the use of the excess-acetylene flame for preparing the scarf is distinctly a metallurgical development. Obviously, such a flame will prevent oxidation, and even reduce iron oxides within certain quantitative limits. Thus the flame tends to fulfil one of the important requirements, namely, cleanliness of the junction surface.

However, still another phenomenon is involved. Steel at temperatures in excess of 1100° C. is rapidly carburized by acetylene, with a resulting surface film of high-carbon material. It is well known in metallurgy that the presence of 1.7 per cent of carbon (or more) reduces the solidus temperature of mild steel by 325° C. to approximately 1150° C., so that a relatively low temperature will suffice to produce a surface within the liquidus-solidus range. Because the surface can be produced at a relatively low temperature, its existence in a uniform and well-defined manner is guaranteed, and it will be noted that this is accomplished without melting any appreciable amount of the base metal itself. As the weld-metal rod is added in a molten state, the carbon diffuses rapidly, with consequent partial solidification at the initial surface and the formation of a continuously progressive junction surface of the proper character.

All of the above deals with the assurance of mechanical quality, together with speed of welding of the joint. The matter of metallurgical quality is, however, also involved, and naturally carries with it one aspect of mechanical quality. It is necessary that non-metallic inclusions of various classes be avoided in order that the constantly progressing junction surface shall remain free from foreign matter. This is accomplished by the use of proper amounts of silicon and manganese in the welding rod, so that any oxide present is converted to an iron-manganese silicate which will be readily eliminated from the fused pool of metal as the welding progresses. This performs a further function of producing a protective slag which blankets the molten metal and increases the surface tension to a point at which the molten pool may be maintained in position by the force of the properly directed flame. The ternary diagram of the FeO–MnO–SiO_2 system serves as a logical metallurgical guide for the specification of rod analyses. However, the problem of welding rods is not as simple as it might appear from the above.

The application of prepared scarf welding by the oxy-acetylene process with the increased control of all the factors involved, makes it very important that the welding rod used shall be uniform in character and suitably designed for the purpose. Much more than the proper ratio of silicon to manganese is necessary to produce the desired flowing characteristics and protective slag. It is of paramount importance that the rod be free from mechanical and metallurgical defects. This is the steel-maker's problem. As yet, no method is known whereby a specification may be drawn to ensure the desired uniformity, other than actual fusion tests. The tests involve the melting of the end of the rod, making a weld with the rod, and remelting the deposited weld-metal. In this way not only are pipe, inclusions and porosity in the rod proper made evident—should they exist—but also the combination of characteristics which ensure satisfactory welding performance is investigated directly. Blow-holes, inclusions or other defects in the weld proper, are readily apparent in the remelting test, so that a complete check on the rod is obtained. It may seem to some that the testing of every bundle of welding-rod wire in the above manner to ensure quality is an inordinate expense. Experience has proved that this expense is justified many times over by actual performance in welding under a great variety of conditions.

The above principles apply with increasing emphasis to layer welding. This method of welding has become quite popular, particularly in connection with the arc process, using heavily coated electrodes. In carrying out such layer welding, it has been necessary to allow the work to cool after each layer, and, painstakingly and laboriously, to remove slag and surface oxide and otherwise to prepare a bright clean surface for the reception of the next layer. This, of course, carries with it a certain loss of time and energy. By following the principles of the metallurgically improved type of gas welding described above the preparation of the surface of the first deposited layer is automatically accomplished in the process of depositing the subsequent layer; i.e., the iron oxide is reduced and the fused oxides forming a slag on the surface are melted and blown back by the torch, thus rising to the top of the advancing pool of weld-metal of the second layer.

The second and third fundamental requirements listed in the introductory paragraph pertain to the physical properties of weld-metal and the base metal adjacent thereto. Let us first consider the metallurgical effect of fusion welding on the base metal. Here, the optimum characteristics are a function of two factors: Metallographic state and internal stress condition. The total amount of plate material held at a temperature in excess of 1150° C. should be a minimum in order to avoid grain growth and reduced ductility in the joints which are not subject to normalizing after welding. Again, the maximum amount of material should be maintained at a temperature between 500° C. and the critical transformation temperature on cooling the metal—this to reduce internal stress in the material to a minimum. It is obvious that with the normal heating and fusing of the base metal the two principles imply contradictory conditions, but here again the use of a prepared scarf with a lowered solidus temperature offers a solution. Because of this lower solidus the temperature of the scarf proper is markedly reduced, so that the zone above 1150° C. is likewise greatly reduced or eliminated. By the use of proper preheating flames, a reasonably large proportion of the material is kept in the desired stress-relieving zone. Thus, strain with accompanying subsequent strain age-embrittlement is reduced to a minimum in those welds which are not subjected to complete stress-relief after the welding. The use of autogenous layer-welding, involving the application of an additional layer before the previous layer has cooled below a red heat, is entirely consonant with the above arguments, because the zone above 1150° C. is reduced to a minimum and the

zone at a temperature just above 500° C. is markedly increased in extent. Unfortunately, the same cannot be said of that layer-welding method in which the first layer is allowed to become cold before the application of the next layer. The combination of proper preheating flames and properly disposed oxyacetylene layer-welding results in less internal stress than any other known method of fusion welding.

The whole subject of the heat treatment of welds to improve the physical properties of the weld-metal and the adjacent base metal is of prime importance, and industrialists have gone to great lengths to carry out the heat-treating processes in an efficacious manner, the favorite method being to stress-relieve the entire structure by heating in a furnace at 550° C. While weld-metal as deposited, either by the oxyacetylene or any of the electric fusion welding processes, has physical properties suitable for many engineering applications, the fact is generally recognized that these properties may be greatly improved by normalizing. In layer-welding by any of the processes in question, the initial layers are normalized by heat from the deposition of subsequent layers. It should be pointed out that this is also true in the oxyacetylene layer-welding mentioned above, because subsequent layers are deposited only after the initial layers have cooled to below their transformation temperature. However, regardless of the welding method used, the last layer deposited is not normalized. In view of the fact that this is the surface, and as such carries the maximum stress in any service involving bending moments, the normalizing of this layer would seem to be obligatory where optimum properties are desired.

It has been argued by some that the main function of the normalizing treatment is grain refinement, and that such grain refinement is accomplished by stress-relieving, i.e., heating to 550° C. This is based on the assumption that sufficient cold-work has been produced in the top layer on cooling so that heating below the critical temperature causes recrystallization. That this actually occurs in many arc-process welds cannot be disputed; but let us consider the matter further from the viewpoint of the metallurgist. It has been well and frequently demonstrated that the amount of cold-work necessary to produce recrystallization without excessive grain-growth implies a critical relationship between the amount of cold-work and the annealing temperature. In the case in question the annealing temperature is fixed, whereas the amount of cold-work may vary from nothing to quite an appreciable amount, depending upon the process of welding and the mechanical conditions involved, such as the thickness of the plate, the size of the structure, the length of the seams, the speed of the welding, etc. The strain is produced only by internal stress due to temperature gradients, particularly on cooling. Dependence upon this variable stress as a factor in recrystallization represents the poorest type of practice to the metallurgist. From the preceding arguments, we may advance a conservative opinion that in order to ensure optimum properties in the last layer deposited in any type of fusion welding a normalizing treatment is necessary. This is readily accomplished by using a heating torch after the last layer is deposited. It should be further considered that this normalizing is obtained without the setting up of steep temperature gradients, so that a stress-relieving treatment after such a local normalizing would be redundant. Thus, local normalizing—that is, normalizing of the weld and the immediately adjacent area only—is a satisfactory process to be highly recommended when low internal stress conditions exist.

A distinct contrast is the matter of local normalizing of stress-relieving of highly stressed structures. In the opinion of many, this is to be seriously condemned. The object of stress-relieving is to reduce internal stress so that the structure in question is not rendered less ductile by its presence. Local stress-relieving accomplishes this in so far as the material heated to temperatures in excess of 500° C. is concerned. However, it must be realized that stresses set up during the welding process, if at all serious, cause strains not only in the material immediately adjacent to the weld but for some distance in the plate as well. On local stress-relieving, the portion of the plate immediately adjacent to the stress-relieved zone is subjected to a temperature of approximately 400° C. for an appreciable length of time. This exposure, combined with the above-mentioned strains, results in strain age-embrittlement, so that instead of really putting the material of the structure in a more ductile condition the local stress-relieving treatment often results in lowering the ductility of the structure as a whole. This condition occurs much more frequently in arc-welding, where the initial stress set-up is of a much greater order of magnitude. Thus, local stress-relieving should never be used, and local normalizing should be used only where the stresses set up by the welding are of a lower order of magnitude, such as would be obtained by the proper procedure-controlled oxyacetylene welding following the principles described in the foregoing.

Conclusions

The above discussion may be summarized and certain definite conclusions drawn. While the first of these applies particularly to oxyacetylene welding, the remainder apply equally as well to all other types of fusion welding:

(1) Mechanical soundness may best be obtained by preparing the surface of the parts to be joined by the excess-acetylene flame and using welding-rod metal of the desired flowing and slag-forming qualities as called for by the constitution of the $FeO–MnO–SiO_2$ slag system.

(2) Optimum physical properties and freedom from internal stress result from normalizing the weld and area adjacent thereto, although such optimum properties may not be necessary for many applications.

(3) Local normalizing may be applied without danger in the absence of high internal stress, and this internal stress, produced by steep temperature gradients, may be reduced to a minimum by lowering the maximum welding temperature and by proper heat distribution.

(4) Complete normalizing or stress-relieving of the entire structure should be considered essential if high internal stress exists.

In order to meet the manifold requirements for optimum results, it is evident that any welding process should admit of a certain flexible and independent control of the factors involved. Moreover, a review of these factors indicates that they are largely a function of the atmosphere, protective coating and temperature distribution at any instant or at any location during the welding. In that autogenous welding allows maximum control of the atmosphere, type of slag and selection of heat distribution in the welding, the applications of metallurgical principles to this process should be most fruitful. Thus, it is not surprising that recent developments have evolved a welding technique and resulting weld which meet all of the requirements as to quality, nor is it surprising that the speed of welding with this technique is such as to ensure marked economy.

Direct Measurement of Contraction of Butt Welds*

By O. M. HARRELSON† AND SEARCY B. SLACK††

WHILE contraction, or shrinkage, is one of the well known properties of welds, there is comparatively little information available as to the amount of this contraction and the factors affecting it. If the amount of contraction in a weld could be predetermined it would frequently be of help in design, and would make possible the computation of stresses in cases where provision cannot be made for shrinkage.

Description of Apparatus

A simple piece of apparatus for the direct measurement of contraction in butt welds has been made, and tests with it carried out in the welding laboratory of The Georgia School of Technology. The apparatus consists essentially of a pair of spring tongs with legs 24 inches long of $^1/_2$ inch square cold rolled steel. At the lower end, the legs are welded to a block, cut to form a spring; the specimen to be welded is fastened between two screws passing through the center of the legs; at the upper end a measuring dial is fastened to one of the legs with the plunger of the dial resting against the other leg. To protect the dial from the spatter and heat of the weld, and to limit the movement of the legs, a thin plate was fastened to one of the legs just below the dial; the other leg passed through a hole in this plate. Thin sheets of asbestos, through which the clamping screws passed, were placed between the specimen and the inside of the legs. The apparatus with a specimen in place is shown in Fig. 1.

As the distance from the spring to the specimen was one half of the distance from the spring to the dial, the dial measured twice the contraction in the weld. The spring between the legs exerted a pressure of about 15 pounds on the specimen. Shallow holes were drilled in opposite sides of the specimen to prevent slippage, and to insure a good bearing for the screws holding it.

While welding was in progress, and to some extent while the apparatus was cooling, unequal distribution of the heat in the legs caused them to warp and affect the dial readings. To guard against error from this cause, the initial reading was taken before welding started, and the apparatus and weld were cooled off, and sufficient time allowed for the equal distribution of temperature, before the final reading was taken.

The temperature of the material being welded was measured by thermocouples and a potentiometer. The thermocouples were insulated by porcelain, and placed in small holes bored in from the sides of the specimen to within about $^1/_8$ inch from the surface to be welded. One couple was placed on each side of the weld and the readings of the two couples were averaged. The apparatus was set up as shown in Fig. 2.

Two of the curves showing temperature and contraction for a gas weld and an arc weld are shown. The temperature measured would increase as the point of welding approached the hole where the thermocouple was placed and would decrease as the welding moved away. As has been pointed out, intermediate readings of shrinkage as measured by the dial, were affected somewhat by warpage of the tong legs, the curves, however, give rather interesting information and apparently indicate that most of the contraction occurs just after the weld is connected.

Shape of Specimens

The specimens were cut with a torch from a solid plate and most of them were of the shapes shown in Fig. 3. The gap to be welded was cut in a "V" with an open bottom from $^1/_8$ to $^5/_{16}$ in. and with sides at an angle of 50 to 55 degrees with horizontal. All welds were made in a horizontal position.

Fig. 1—Measuring Apparatus with Specimen Fastened at Center, and Spring Block at the Right

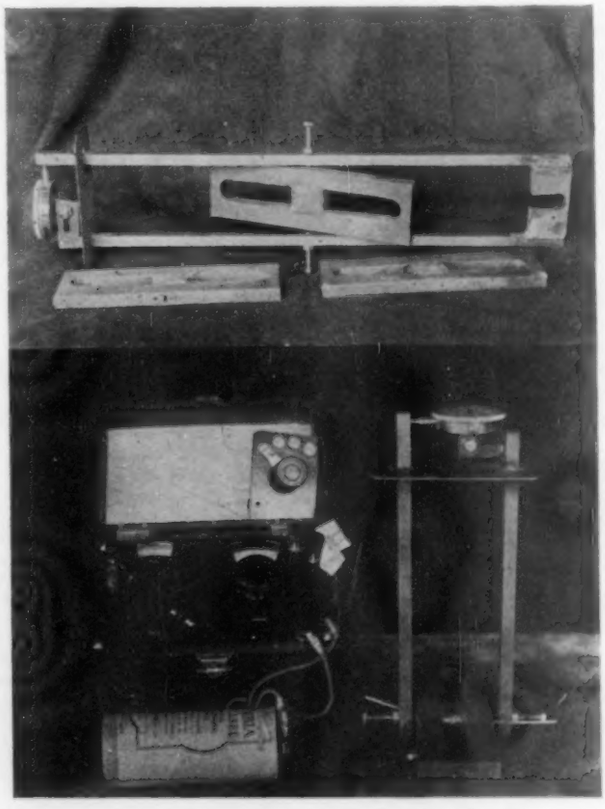

Fig. 2—Apparatus Setup with Thermo Couples in Place

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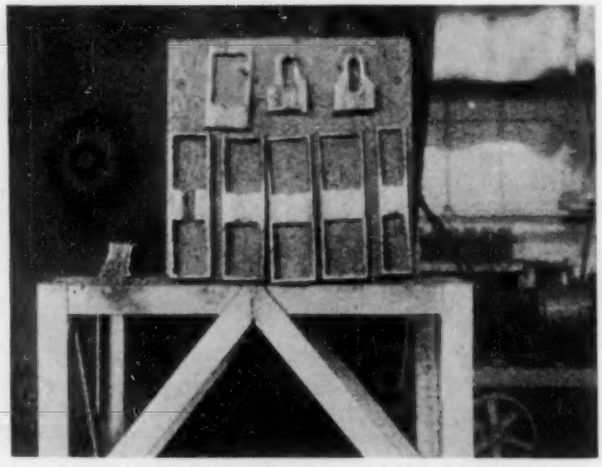
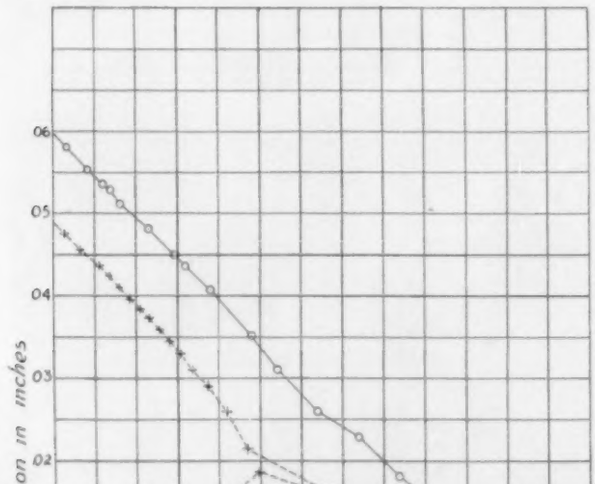


Fig. 3—Various Shapes of Specimens Used. All Have Been Welded Except the One in Lower Left Corner

On some of the specimens the thickness of the sides was increased to 1 inch, some were cut in "C" shape with the weld at the open end and, on a few, blocks to be welded together were tack-welded to the sides of a frame. The shapes of the specimens and thickness of frames, apparently had little effect on the shrinkage of the weld.

Under some of the specimens, a strip of metal was placed so as to close the open gap between the blocks to be welded. These strips served the same purpose as a backing up strip which is sometimes used. These strips had no noticeable affect.



Welding

The rods used for the electric arc welding were of bare steel wire $^{5}/_{32}$ inch in diameter. A current of 150 to 175 amperes using straight polarity was used.

For the oxyacetylene welds, a number 9 tip was used on the $^{3}/_{4}$-inch material, a number 7 tip on the $^{1}/_{2}$-in. material and a number 5 tip on the $^{3}/_{8}$- and $^{1}/_{4}$-inch material. Both high and low test welding rods were used, but information available does not justify a comparison of the two types of rods.

Results

The results of these tests are shown in the accompanying table and curves. Other curves taken were similar but have been omitted for clarity. These results indicate a contraction of from 0.024 to 0.054 in. for arc welds and of from 0.052 to 0.086 in. for the gas welds.

Measured Contraction of Butt Welds

Electric Arc Welds		Oxyacetylene Welds	
Thickness of plate, inches	Contraction, thousandths inches	Thickness of plate, inches	Contraction, thousandths inches
$^{1}/_{4}$	31	$^{1}/_{4}$	58
$^{1}/_{4}$	26	$^{1}/_{4}$	62
$^{1}/_{4}$	24	$^{1}/_{4}$	54
$^{1}/_{4}$	39	$^{1}/_{4}$	52 Av. 56
$^{1}/_{4}$	39 Av. 32	$^{3}/_{8}$	55
$^{1}/_{2}$	36	$^{3}/_{8}$	68
$^{1}/_{2}$	44	$^{3}/_{8}$	53
$^{1}/_{2}$	54	$^{3}/_{8}$	58 Av. 58
$^{1}/_{2}$	53	$^{1}/_{2}$	86
$^{1}/_{2}$	47	$^{1}/_{2}$	73
$^{1}/_{2}$	40	$^{1}/_{2}$	78
$^{1}/_{2}$	37	$^{1}/_{2}$	82 Av. 80
$^{1}/_{2}$	29	$^{3}/_{4}$	71
$^{1}/_{2}$	25	$^{3}/_{4}$	83
$^{1}/_{2}$	45	$^{3}/_{4}$	71 Av. 75
$^{1}/_{2}$	37		
$^{1}/_{2}$	41		
$^{1}/_{2}$	48 Av. 41		
$^{3}/_{4}$	28		
$^{3}/_{4}$	26		
$^{3}/_{4}$	28		
$^{3}/_{4}$	28		
$^{3}/_{4}$	25		
$^{3}/_{4}$	29 Av. 27		
$1^{1}/_{4}$	44		
$1^{1}/_{4}$	47		

It is recognized that these results are far from satisfactory as the factors affecting the contraction of the welds have not been established and there is a wide variation in the amounts measured in the different specimens of the same thickness. These data should be of interest as indicative of the approximate range of the amount of contraction in butt welds.

The hypothesis is advanced that the amount of contraction is proportional to the size of the pool of molten metal in the arc crater, or under the flame of the torch, while the weld is being made—the larger pools producing more contraction. Suggestions and criticisms are invited to guide further work.

Cast Iron to Monel

By W. P. DURGLUND†

Problems Solved By Use of Cast Iron Rod and Bronze-Welding Technique

FOR simplest joining of dissimilar metals, the obvious thing to do is to bronze-weld. In certain cases, however, the finished article may have to resist the action of corrosive fluids that will attack brass or bronze. Obviously a bronze-welded joint will not do for this purpose at all, in spite of its desirable qualities in general as a joining method. The answer to this problem is, however, quite simple, although it is one which may not be generally known. Very simply, it means utilizing the same property of metals that makes bronze-welding possible. It depends on the fact that a metal of lower melting point tends to "sweat" to the clean, heated surface of a metal of higher melting point. An explanation of how this type of work can be done may prove to be useful in other cases.

Monel Metal Welded Container with a Cast Iron Plug "Sweated" in the Bottom

An industrial research institution required a piece of equipment for freezing a solution containing caustic soda. A simple piece of equipment was devised similar to an ice-cream freezer. To resist the corrosive action of the caustic soda it was decided that Monel metal should be used for the container and that the joints be gas welded with Monel metal welding rod.

It was necessary to have a cast-iron plug on the bottom of the can through which a rotating arm would fit. This plug had to set completely through the container in order to permit operation of the dasher.

The welding problem was how to weld the cast-iron plug into the hole in the end of the Monel metal can. As caustic soda will attack brass and bronze, it was obviously inadvisable to bronze-weld the cast iron fitting to the can. The problem was solved quite simply by using cast-iron welding rod with a technique similar to bronze-welding. The melting point differential between cast iron (about 2150°F.) and Monel metal (2480°F.) made the job possible.

The bottom of the container was preheated with the oxyacetylene flame to permit it to expand and to anneal the Monel metal. With the iron fitting in place, the heat was applied to both plug and can simultaneously. When the Monel metal reached a cherry red heat, the flame was concentrated on the fitting, bringing it to the fusion temperature. Cast-iron welding rod and Brazo flux were used to make the joint. There was definite fusion between the cast-iron welding rod and the cast-iron plug, but the action between the plug and the Monel metal container was a "sweating," quite similar to the tinning action in bronze-welding. This gave a good union of the metals and a strong joint.

For such work, the heat must be carefully controlled to carry through the job. Care must be taken to remove surface oxides by the use of flux. With the oxides removed from the surfaces of two dissimilar metals, both of which have different melting points, the material of lower melting point will "sweat" or adhere to the surface of the higher melting point metal to give a joint which is very similar to the typical bronze-welded joint. This fact can undoubtedly be used to solve many otherwise troublesome problems.

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Corrosion Resistant Steels in the Petroleum, Chemical and Allied Industries*

By H. LEROY WHITNEY†

THERE are two factors which govern whether or not corrosion resisting steels are to be used in the petroleum, chemical and allied industries, to wit, Economics and Ability to Accomplish Results.

Economics

The first of these controlling factors is Economics. Accordingly, in estimating the cost of equipment subject to corrosion, the corrosion rate, type of material and expected life must be established to determine the lowest possible overall cost.

Among many, another factor which governs the economics of the situation is purity and color of product. This factor is very important in the chemical and food industries and the question to be determined is whether it is cheaper to use a material which will discolor or impart impurities to the media being processed and to remove the discoloration or impurities by further processing, or to use a corrosion resistant material which will impart neither discoloration nor impurities.

The cost of actually replacing corroded parts and the loss of production due to shut downs to replace cor-

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roded parts must always be reckoned with in obtaining the true economic answer.

Ability to Accomplish Desired Results

In defining ability to accomplish desired results, there are many instances where a high alloy steel must be used on account of temperature, and other cases where the purity of product demands a corrosion resistant steel.

Welding and Testing of Alloy Steels

The welding of high alloy steels, such as used in the petroleum and chemical industries requires some very drastic departures from established welding procedure and heat-treatment. Each alloy has its own idiosyncrasies, and before a given alloy is fabricated into a pressure vessel these idiosyncrasies should be definitely established and methods developed to effectively take care of them. This is of primary importance to protect the lives of those who are to work around the vessels in service, but it is also important to protect the purchaser's interest in providing him with a vessel which will have the service life expected.

Since these alloy steels are quite expensive, the cost of welding and testing full sized pressure vessels for experimental purposes is almost prohibitive. The primary reason, of course, for wishing to weld full-sized pressure vessles is to determine their fabricating characteristics under shop conditions. The physical properties and corrosion resistant properties of the weld and welded joint may be determined on welds made on smaller specimens. In order, however, to simulate as nearly as possible conditions which may be met in regular shop production, small diameter vessels with a high ratio of thickness to diameter may be fabricated in such a way that the shrinkage strains in welding are exaggerated to a point where it is felt that the normal difficulties of shop fabrication are simulated quite closely and in fact very probably exceeded.

In investigating the fabricating characteristics of several of the high alloy materials, The M. W. Kellogg Company built a vessel of each alloy selected, 14 in. inside diameter x 2 ft. long and $^1/_2$ in. thick. After the straight weld was made and X-rayed, the vessel was cut in half transversely, and a $^1/_2$ in. thick disc 14 in. in diameter was placed under the center of a girth weld between the two halves of the vessel. In welding the girth seam, care was taken to fuse the edges of the plates into the solid disc below. The weld was then completed in the normal way. The idea of the solid disc below the girth weld was to exaggerate as much as possible the strains produced by shrinkage in the weld. It was felt that if a vessel constructed in the above manner could be made without unusual difficulties, that in all probability most of the ordinary types of pressure vessels could also be made without difficulty. If, however, fabricating troubles did develop in the smaller test vessel, it would indicate that they might also develop in fabrication of a full-sized vessel.

In addition to the fabricating properties as determined by the above test, a complete chemical analysis of deposited weld metal and base plate was made. The vessel was heat-treated in accordance with recommendations made by the manufacturer of the steel. In some cases additional heat-treatments were added to determine their effect. After heat treatment, physical tests were run on all-weld-metal tension bars, reduced tension bars, bend bars and Charpy impact tests were made on weld, adjacent area and base metal. A thorough microscopic examination was made of welded joint and base metal at 100 X and 1000 X. Corrosion resistance was determined by the Huey test, each sample being run for five 48-hour periods in 65% boiling nitric acid. Tests to determine the susceptibility to inter-granular corrosion were also conducted. These tests consisted of immersion of the sample in boiling 3% $CuSO_4$-10% H_2SO_4 for 72 hours, after which the sample was removed and bent as a free bend, elongation and angle of bend being measured and the condition of the fracture, if it occurred, noted.

The above tests are probably the best accelerated corrosion tests known today, but it must be emphasized that they can by no means be relied upon to give the corrosion resistance in all media. Where possible, samples should be tested under actual service conditions because this is the only way of getting actual operating data. This usually requires a great length of time and some sort of accelerated test must be resorted to.

Rockwell hardness determinations were made throughout the welded area and in the base metal of each material.

A complete report covering the welding characteristics of the rod and any troubles encountered was kept in each case and formed a part of the test data.

One very important property to determine in any untried material is its susceptibility to temper embrittlement. As mentioned before, a great deal of trouble was experienced in the oil industry with straight 4–6% chrome because of this material's susceptibility to temper embrittlement after service at high temperatures. The only accelerated test known by the author to determine this property of a material is one which was developed by Greaves and Jones in England some years ago, to be applied to tool steels. This test does not necessarily apply to all alloys, but for the lower alloy materials and for plain carbon steels, the results obtained check the results recorded from service data. It is, therefore, recommended that before a new material is put into service at high temperatures that its susceptibility to temper embrittlement be determined if possible.

Materials at Sub-zero Temperatures

In the petroleum and chemical industries pressure vessels and tubes have to operate at sub-zero temperatures and as it is a well known fact that certain materials lose almost all their resistance to shock at low temperatures, their resistance to shock at operating temperature should be investigated thoroughly in addition to their weldability.

In closing I wish to emphasize the fact that too much care can not be exercised in the investigation of any new material before it is put into service. Such investigations protect not only the ultimate consumer, but the fabricator as well, and after new materials have been installed careful operating records should be kept so that the operating data of experience can be added to the data based on research. Experience and research should go hand in hand and I again make a plea for closer cooperation between the manufacturer of the material to be fabricated, the fabricator and the consumer in problems of research and development.

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Wire. Welding Fine Wires, O. Zdralek and J. Wrana. Elec. Rev. (June 21, 1935), vol. 116, no. 3004, p. 898. Translation of article previously indexed from Elektrotechnische Zeit May 23, 1935.

BOOKS

"Thermit Welding—Industry's Master Maintenence Tool," is the title of a new illustrated sixteen-page booklet just published by the Metal & Thermite Corporation, 120 Broadway, New York, N. Y.

The new booklet describes Thermit Welding, an aluminothermic process which has been successfully employed for more than thirty years in the welding of heavy sections of ferrous metals. The actual welding of street railway and railroad track and the repair of large machine parts, huge marine castings, crankshafts and similar articles by the Thermit Process are also covered thoroughly. Particular attention is given to the economy and permanency of Thermit repairs and actual cost data are given in a number of instances.

A copy of the booklet may be obtained by writing to the Metal & Thermite Corporation at the above address.

TENTATIVE PROGRAM
FIFTEENTH FALL MEETING
AMERICAN WELDING SOCIETY
SEPTEMBER 30—OCTOBER 4, 1935
Palmer House, Chicago

Monday, September 30th

Morning

REGISTRATION

Facilities will be provided throughout the week from 9:30 A.M. to 5:00 P.M., commencing Monday, September 30th.

Afternoon

OPENING SESSION

1:45 P.M. Introduction of President of American Welding Society by D. C. Wright, Chairman, Chicago Section.

Address of welcome by local celebrity.

Response.

2:00 P.M. Presentation of Miller Memorial Medal Award.

TECHNICAL SESSION

2:30 P.M. Presiding Officer—J. J. Crowe, President.

"Bridge Welding—A Review of the Literature," by F. H. Frankland, Vice-Chairman, Committee to Study Welding of Highway and Railroad Bridges.

"Nitrogen in Metallic Arc Weld Metal," by Dr. J. W. Miller, Reid Avery Co.

Evening

6:30 P.M. Dinner Meeting, Board of Directors, Palmer House.

Tuesday, October 1st

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—John Cornelius Penn, Dean of Engineering, Armour Institute of Technology.

FUNDAMENTAL RESEARCH IN WELDING

"Spot Welding Problems," by J. H. Zimmerman, Massachusetts Institute of Technology.

"Bend Testing of Welds—A Summary," by M. F. Sayre, Union College.

"Advantages of Welding in Continuous Structures," by Inge Lyse, Fritz Engineering Laboratory, Lehigh University.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—C. A. Adams, Director, American Bureau of Welding.

FUNDAMENTAL RESEARCH IN WELDING

"Arc Welding with Pure Iron Welds," by Gilbert E. Doan, Lehigh University.

"Investigations of Residual Stresses," by R. E. Jamieson, McGill University.

"Low Temperature Tests of Welds," by Otto Henry, Brooklyn Polytechnic Institute.

"Creep Tests of Welds," by N. F. Ward, University of California.

Evening

7:30 P.M. Palmer House. Conference and Meeting of Fundamental Research Committee, American Bureau of Welding—H. M. Hobart, Chairman, presiding.

This conference is scheduled for the benefit of university research workers in the fundamentals of welding.

Wednesday, October 2nd

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—D. C. Wright, Chairman, Chicago Section.

"Tests to Determine the Feasibility of Welding the Steel Frames of Buildings for Complete Continuity," by W. M. Wilson, University of Illinois.

"Welding All-Metal Radio Tubes," by M. L. Eckman, Thomson-Gibb Electric Welding Co.

"A New General-Purpose Meter for Resistance Welding," by C. Stansbury, Cutler-Hammer, Inc.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—G. T. Horton, President, Chicago Bridge & Iron Works.

SYMPOSIUM ON METHODS OF MINIMIZING DISTORTION

1. Pressure Vessels
   J. T. Phillips, Foster Wheeler Company.
2. Repair Welding
   Geo. Hettrick, President, Anchor Welding Service Inc.
3. Light Gage Steel
   J. H. Blaha, General Household Utilities Company.

"Machine Torch Cutting and Fabrication of Tool Equipment," by P. H. Danly, Danly Machine Specialties Company.

Thursday, October 3rd

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—Dr. W. M. Mitchell, Illinois Steel Co.

SYMPOSIUM ON LOW ALLOY STEELS FOR WELDING PURPOSES

"The Development and Use of Low Alloy High Tensile Steels in Welded Construction," by A. E. Gibson, The Wellman Engineering Company.

"Welding of Alloy Steels"—
H. L. Miller, Republic Steel Company.
J. C. Holmberg, Struthers-Wells-Titusville Corp.
Corbin Chapman, Hedges-Walsh-Weidner Co.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—E. Vom Steeg, Chairman, Meetings & Papers Committee.

"Welding of Alloy Steels," by J. C. Hodge, Babcock & Wilcox Company.

"Effect of Generator Characteristics on the Weld," by J. H. Blankenbuehler, Westinghouse Electric & Mfg. Co.

"Electrical Characteristics of the Welding Arc," by S. C. Osborne, Wilson Welder & Metals Co. Inc.

"Resistance Welding of Copper Alloys" by I. T. Hook, American Brass Co.

Evening

7:00 P.M. Annual Banquet—Palmer House.

Friday, October 4th

Morning and Afternoon

INSPECTION TRIPS

Chicago Section is making novel arrangements for the benefit of executives in the metal working industry to visit a group of plants in and around the Chicago district in order to see first hand the varied applications of welding. Probably two routes will be arranged and provision made to accommodate both groups at lunch time. Details as to the plants to be visited will be announced shortly.

WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

Bureau of Navigation and Steamboat Inspection Amended Rules I and II General Rules and Regulations

The above rules were sent to steamship owners, shipbuilders, boiler and steel manufacturers, classification societies and other persons or organizations connected with marine industry, and U. S. Supervising, Traveling, Local and Assistant Inspectors, Bureau of Navigation and Steamboat Inspection, by Director J. W. Weaver of the Bureau of Navigation and Steamboat Inspection, with a circular letter stating that they will become effective July 1, 1935. In the circular letter Director Weaver acknowledged the valuable aid and cooperation of fourteen different organizations.

These rules were prepared with the cooperation of the committee to coordinate marine boiler rules, which was established with the approval of Dickerson N. Hoover, Assistant Director of the Bureau of Navigation and Steamboat Inspection. The members of the committee and the organizations which they represented are as follows:

* W. M. McFarland, chairman, past-president, Society of Naval Architects and Marine Engineers.
H. L. Seward, secretary, Society of Naval Architects and Marine Engineers, and American Bureau of Shipping.
Chas. F. Bailey, National Council of American Shipbuilders.
John L. Crone, Bureau of Navigation and Steamboat Inspection.
D. S. Jacobus, American Society of Mechanical Engineers.
B. E. Meurk, American Steamship Owners' Association.
H. C. E. Meyer, American Marine Standards Committee.

Subcommittees

J. Bergvall, American Bureau of Shipping.
* A. V. Bouillon, American Marine Standards Committee.
J. W. Wilson, Bureau of Navigation and Steamboat Inspection.

The rules sanction the fusion welding of drums or shells. This section was prepared by a Committee on Welding in Marine Construction of the AMERICAN WELDING SOCIETY, and was based on the rules prepared by the A.S.M.E. Boiler Code with the cooperation of the AMERICAN WELDING SOCIETY.

New Copper Alloy†

The Metallurgical Engineering Department of P. R. Mallory & Co., Inc., of Indianapolis, Indiana, has developed in Mallory 3 Metal a material of high electrical conductivity, great mechanical strength and greatly diversified application.

This metal is an alloy consisting predominantly of copper and is the equal of copper in coefficient of resistivity, coefficient of expansion, modulus of elasticity and corrosion resistance. The electrical conductivity of forgings and rods from the metal is rated at 80 to 85%, that of copper or better. Sand castings of the metal will have an electrical conductivity of 75 to 85% that of forged copper.

The metal may be substituted, with few exceptions, for brass, copper, bronze or even structural steel. It has already been used extensively for spot welding tips, flash welding dies and seam welding wheels. The castings have proved remarkably successful in numerous applications where material of high strength and high conductivity is required.

Its high electrical conductivity and strength equal to that of mild steel may be used to replace bulkier copper parts, effecting a saving in weight and size. It can also be used as scoreless commutator segments in motors and generators, overhead wire for electrical railways, telephone and telegraph service as its great strength will resist breakage from sleet and wind. Its high heat conductivity will permit its use under heat conditions where copper softens, such as welding wheels and tips, and hot water heating coils. It may be used successfully as a welding tip or wheel where proper water cooling is not obtainable.

International Congress Oxyacetylene Welding

The 12th Congress marking the 50th Anniversary of the Industrial Production of Oxygen in Great Britain and the Centenary of the Discovery of Acetylene will be held in London, June 8–13, 1936, under the direction of The British Acetylene Association. Previous Congresses were held in the following cities and years: Berlin 1898, Budapest 1899, Paris 1900, Liège 1905, London 1908, Vienna 1911, Rome 1913, Paris 1923, Brussels 1927, Zürich 1930, Rome 1934.

The general organization of the Congress is under the direction of the British Acetylene Association which, as in the case of former Congresses, is collaborating with the Permanent International Committee of Acetylene, Oxyacetylene Welding and Allied Industries. The British Organizing Committee is appointed by the British Acetylene Association.

The purpose of the Congress is the scientific, technical and economic study of questions relating to calcium carbide, acetylene, oxygen, oxyacetylene welding and to their various applications. Other welding processes are admissible in so far as they have a bearing upon the development of oxyacetylene welding and cutting. Complete information in regard to this Congress may be obtained from the AMERICAN WELDING SOCIETY.

Obituary

W. W. Wysor, chief engineer of the United Railways & Electric Company, died in Baltimore, June 30th at the age of 57. Mr. Wysor was well known throughout the industry, and took an active interest in association activities. He was president of the American Transit Engineering Association in 1929–30. Mr. Wysor was educated at the Virginia Polytechnic Institute. Following graduation, he engaged in engineering with railroads in the South, and became connected with the Baltimore system in 1916 as assistant chief engineer. He was made chief engineer in June 1917. He served as a member of the Executive Committee of the Committee on Welded Rail Joints of the American Bureau of Welding during its existence.

Important Notice to Associate Members

In a recent issue of the JOURNAL we announced a change in the By-Laws of the AMERICAN WELDING SOCIETY dealing with the classification of members.

The change in the classification of the "Member" grade is of particular importance to Associate Members. The requirements for this grade have been raised considerably so that this classification now reads:

"Members" being individuals not less than 23 years of age who shall have been for at least three years engaged in work having a direct bearing on the art and science of welding and shall have made some contribution to the science and art of welding. Members in good standing of any major engineering society are also eligible.

The annual dues have been reduced to $15.00.

Present members in this grade will not be disturbed. A short period of grace will be allowed present members to join the "Member" grade before this requirement becomes effective. Associate Members are urged to take advantage of this opportunity at the earliest opportunity. Upon request the Secretary will issue a bill for the prorata difference in membership dues of the two grades for the unexpired term of present Associate Members.

* Deceased.
† From a News Release.

SECTION ACTIVITIES

BOSTON

The meeting held April 26th, at Massachusetts Institute of Technology, with a large attendance was the last scheduled meeting of the Section until Fall. A program of meetings for the coming season is being prepared by the Meetings and Papers Committee. The first Fall meeting will probably be held the third Friday in October.

CLEVELAND

The following are the officers elected for the Cleveland Section for the ensuing year:

Chairman—A. E. Gibson, Wellman Engineering Co.
1st Vice-Chairman—Dr. J. C. Hodge, Babcock & Wilcox Co.
2nd Vice-Chairman—Wm. G. Wehr, Cleveland Crane & Engineering Co.
Secretary-Treasurer—Edw. T. Scott, Cleveland School of Welding, Inc.

BALTIMORE

The following tentative program has been arranged for the coming year:

Friday, October 18th: "The Basic Requirements for Making Good Fusion Welds."

Friday, November 22nd: "What Do Weld Tests Prove?" Speaker: Mr. Stewart, U. S. Naval Engineering Experiment Station.

Friday, January 17th: "Demonstration of Stress Distribution in Welded Connections by Means of Photoelastic Apparatus."

Friday, February 21st: "Some Practical Aspects of Fusion Welding (Electric Arc, Gas and Carbon Arc)." Speaker: Mr. Ronay, U. S. Naval Engineering Experiment Station.

Friday, March 20th: "Welding of Non-Ferrous Metals, Silver Soldering and Brazing."

Friday, April 17th: "Non-Destructive Methods of Testing Welds. (X- and Gamma-Rays, Arcronograph, Magnetic Analysis, Stethoscope)." Speaker: Dr. Briggs, Naval Research Laboratory.

Special Offer

While supply lasts you can obtain set of two Instruction Manuals at $2.00.

Set includes:
"Manual of Electric Arc Welding" by E. H. Hubert (Regular price $2.00)
and
"American Welding Society Instruction Manuals on Gas, Resistance and Thermit Welding" (Regular price $1.00)

Here is rare opportunity to get these important books at a considerable reduction.

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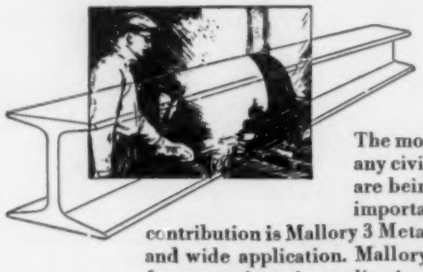

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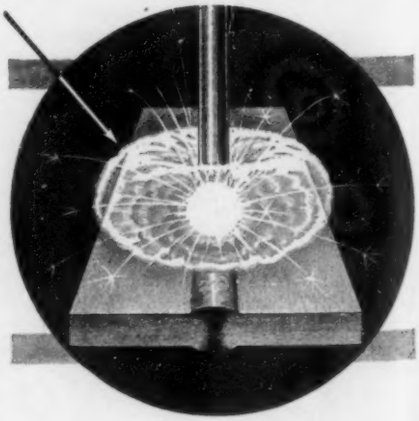
The requirements for good welding are no different from those required in any other step of your production. - - - Quality of materials, speed of application and character of finished work are the important factors. - - - Page Hi-Tensile Electrodes are better electrodes. - - - They are pure metal and are heavily coated. - - - This coating provides a small protecting cloud which closely surrounds and shields the arc—spatter loss is less. A larger amount of actual usable weld metal per inch is deposited, the formation of oxide and nitride impurities is prevented, the weld is completely covered, thereby lowering the cooling rate which in turn increases the ductility of the weld metal. - - - Look to Page for better welding and to the Page Engineering Staff for counsel if your welding problem seems to you to be particularly difficult.



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